

THE EFFECTS OF FORMAL REASONING
ABILITY, SPATIAL ABILITY, AND TYPE OF
INSTRUCTION ON CHEMISTRY ACHIEVEMENT

By

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THE EFFECTS OF FORMAL REASONING ABILITY,
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ON CHEMISTRY ACHIEVEMENT

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The purpose of this investigation was to identify factors that influence achievement in chemistry by comparing the achievement of high school chemistry students who receive a visually enhanced treatment of the topic of balancing equations and conservation of mass with students who receive traditional instruction (without visuals) on the same topics.

Three different visualization tests were administered prior to instruction in order to determine the students level of visual ability. Card Rotation test scores represent the ability to rotate an object in two dimensional space. Hidden Figures test scores represent the ability to disembed a figure from a more complex one. Form Board test scores measures how well students can rotate multiple objects and make a more complex object. The Arlin Test of Formal

Reasoning was administered as a measure of formal reasoning ability. The tests were administered to 116 chemistry students selected from high schools in South Central Florida. The students ranged in age from 16 to 18 years of age.

Analysis of variance, analysis of covariance and general linear model were the procedures used to analyze the data. The analysis of variance results support the hypothesis that chemistry achievement is affected by formal reasoning and the visualization ability as measured by the Hidden Figure test. Also students at the concrete reasoning level did not perform as high as students at the formal reasoning level on the content test. It was also found that chemistry instruction using a greater visual means of instruction increased the achievement of medium and high visualizers, but not low visualizers. These effects were not supported in the analysis of covariance. Student misconceptions relating to atomic/molecular structures were examined and found to be resistant to change. This study has implications for instructional methods and curriculum and supports further research into factors which affect chemistry achievement.

CHAPTER 1 INTRODUCTION

Chemistry touches all facets of our lives. M.H. Gardener writes in *Teaching School Chemistry*:

Since chemistry touches the lives of every individual, (through agriculture, industry, nutrition, medicine, the home environment, etc.) an individual's every moment, awake or asleep, at work or at play, as a youth or adult is directly influenced by the understanding and therefore the utilization he or she can make of chemistry. Scientific discoveries, technological advances, the efficiency of the work force, the exercising of citizen's rights and the quality of life are directly tied to the teaching of chemistry. (p.346)

Despite the acknowledgement of the importance of chemistry, the National Assessment of Educational Progress (NAEP, 1988) report shows that fewer students are taking high school and college chemistry classes. Only 37% of the high school students surveyed had completed a year of chemistry. Sixty-three percent surveyed had taken only half a year of chemistry. In the 1987 High School Transcript Study, 45% of the students surveyed had taken a chemistry course, whereas 90% had completed a biology course. Approximately twice as many students take biology as take chemistry, and about half of those taking chemistry do not complete the year. The NAEP Report (1988) also shows that achievement in high school chemistry is mediocre. This trend has changed little in the last 10 years. The report, A Nation At Risk (NCCE, 1983) reinforces the fact that science achievement in the United States is below standard when compared to other countries, with the U.S. often ranking last.

As a result of this alarming trend, important research relating to chemistry learning and instruction is currently being done (Yager, 1989). Teachers must understand how students learn and make sense of chemistry concepts. They must examine carefully the gaps that exist between the knowledge presented and knowledge gained. Attempts to understand the issues underlying disappointing chemistry enrollments and achievement have resulted in a focus on the following research questions.

1. How is chemistry being taught today?
2. How can we improve the teaching of chemistry?
3. What teaching approach is best for certain chemistry topics?
4. How are teaching theory and practice related?
5. How do students learn the facts, concepts, etc. that make up chemistry?
6. What barriers limit students from achieving in chemistry?
7. How can chemistry be made more relevant to students' lives?
8. How do teachers motivate students in chemistry?
9. How are chemistry, technology, and society related?
10. How should we assess students in chemistry?

Although each question is important, this study focuses on the general questions of three, five, and six. These three questions were selected based on the research described below. This research examines the impacts of chemistry students' misconceptions, visual spatial ability, and formal reasoning ability on chemistry achievement.

Misconceptions

Studies of high school student comprehension of chemical concepts have shown that students still exhibit misunderstanding and have trouble

explaining abstract concepts even after sustained instruction (Yarroch, 1985; Gabel, 1993). Research studies focusing on the gas laws, equilibrium, balancing equations, and the particulate nature of matter have all shown that these misconceptions are difficult to change (Gabel, 1993; Yarroch, 1985). A majority of students from elementary through college have alternative conceptions about atomic and molecular models (Ben-Zvi, Eylon, & Silberstein, 1986; Novick & Nussbaum, 1981; Osborne & Cosgrove, 1983). Chemical educators believe that the understanding and use of atomic and molecular concepts are important in teaching chemistry (Haidar & Abraham, 1991). Educators also believe that student understanding of the concepts of the atom and molecule is fundamental to learning other chemistry concepts such as chemical bonding, chemical reactions, ions, and states of matter (Ben-Zvi, Eylon, & Silberstein, 1986; Griffiths & Preston, 1992). Looking into the reasons behind these alternate conceptions allows us to look at both how students learn chemistry and how chemistry is taught.

Visual Spatial Abilities

Although technical vocabulary and the use of symbols underpins all of chemistry teaching and learning, other important aspects include the visual ability of the learners and use of visual models in instruction. Chemistry students are often required to visualize abstract concepts such as atoms and molecules. Students must observe at the macroscopic (phenomena) level and relate these changes to the microscopic (atomic/molecular) level. Ben-Zvi, Eylon, and Silberstein (1982, 1986) found that students have difficulty making this transition.

Instruction in chemistry relies heavily on two and three-dimensional models describing concepts. The level of spatial ability a student has plays an important role in the success of his understanding these abstract concepts.

Formal Reasoning Ability

Lawson and Renner (1975) identified two concept categories: concrete and formal. They found that formal concepts could not be learned by concrete operational students. These findings were corroborated by Cantu and Herron (1978) in their study of chemistry students. Marek (1986) and Simpson (1986) also found that concrete operational students could not understand formal concepts. Lawson and Thompson (1988) stated that concrete operational students also have trouble distinguishing between a correct concept and a misconception if the concept is at a formal level. Research has shown that the majority of students in chemistry are at the concrete operational level, whereas understanding of the abstract concepts covered in high school chemistry classes often requires formal reasoning.

The use of computers and video technology in the classroom has renewed interest in visual spatial aptitudes, the relationship between visual spatial aptitudes and formal reasoning, and the use of visual models for instruction. A large base of research shows that there is a relationship between reasoning ability and visual spatial aptitudes (Kail & Pellegrino, 1985; Litzkow, 1991). Litzkow (1991) found a curvilinear relationship between formal reasoning ability and performance on the Card Rotation Test and the Form Board Test. The Card Rotation Test and Form Board Test are two standard visual spatial ability tests for spatial orientation and spatial visualization.

With these factors in mind, a study of the impacts of prior misconceptions, visual spatial ability, formal reasoning ability, and instruction in these three areas on learning chemistry concepts at the high school level seems appropriate.

Purpose of the Study

The purpose of this investigation was to identify factors that influence achievement in chemistry by comparing the achievement of high school chemistry students who receive a visually enhanced treatment of the topic of balancing equations and conservation of mass with students who receive traditional instruction (without visuals) on the same topics.

Procedures

The subjects in the study were students currently enrolled in chemistry at three different high schools. Two classes of chemistry for three different chemistry teachers made up the sample. Each teacher instructed a control group and an experimental group. The subjects in the control group followed the traditional chemistry curriculum on the topic of conservation of mass and balancing of equations. The subjects in the experimental groups experienced a highly visual presentation of these topics. This included the use of three-dimensional visual models and two-dimensional drawings. The primary difference in the treatments was the mode of presentation. Each treatment lasted for 3 weeks.

Research Questions

Five research questions were investigated in this study:

1. Will chemistry achievement be greater for a highly visual treatment of a topic in chemistry compared to achievement following traditional treatment?
2. Will the difference in mean posttest content scores for the two

treatments of the chemistry topic change depending upon the various levels of student spatial ability?

3. Will the difference in mean posttest content scores for the two treatments of the chemistry topic vary according to formal reasoning level of students?

4. Will student visual spatial ability and formal reasoning ability influence achievement?

5. What changes in conceptions regarding atoms and molecules occur as a result of a visual spatial instruction?

Research Hypotheses

To answer the research questions the following null hypotheses will be tested.

1. There is no significant difference in the effectiveness of treatment as measured by the means on the student content posttest.

2. There is no significant difference in effectiveness of treatment as measured by various levels of student spatial ability (low/medium/high).

3. There is no significant difference in effectiveness of treatment as measured by formal reasoning level (low concrete, high concrete, transitional, low formal, and high formal) of students.

4. There is no significant difference in effectiveness of treatment when both formal reasoning ability and visual spatial ability interactions are examined.

5. There is no change in student's comprehension of atoms/molecules as it relates to conservation of mass and balancing of equations.

Definition of Terms

Terms have many meanings even within a specific discipline. Therefore, it is necessary to define specifically the meanings of the various terms used in this study.

Spatial orientation describes the ability to mentally rotate an object in order to see if two objects are identical. In this procedure, the orientation of the observer is important to the frame of reference.

Spatial visualization describes the ability to rotate several pieces of a figure and identify if the pieces make the correct pattern.

Visual spatial ability is the ability to mentally manipulate visual objects involving a sequence of movements.

Formal operational reasoning is the final stage of Piaget's theory of cognitive development. This occurs approximately after the age of 11 years and is characterized by the student's ability to reason and draw conclusions based on experiences. Students can think abstractly without the use of concrete objects.

Concrete operational reasoning is the middle stage of Piaget's theory of cognitive development. This occurs between the ages of 7 and 11 is characterized by the student's ability to conserve mass in chemical transformations. Students need concrete objects in order to understand and apply the concepts.

Limitations of the Study

The following limitations are a part of the investigation.

1. Generalizations cannot be made for any classes other than the chemistry classes in this study as the study uses a quasi-experimental design with intact chemistry classes.

2. It is assumed that there will be no systematic variation in the instruction between the three teachers and they will all implement the curriculum as instructed.

CHAPTER 2 REVIEW OF RESEARCH

Overview

This chapter summarizes research on the following topics: (a) visual spatial abilities, (b) formal reasoning ability, (c) the relationship between formal reasoning and visual spatial abilities, (d) the learning of chemistry, and (e) chemistry instruction. Each of these topics is important to the understanding of factors influencing chemistry achievement.

Visual Spatial Abilities

Historically, research on visual spatial abilities has been of interest to researchers since the early 1900s. Areas such as architecture, art, psychology, math, engineering and the military were the initial forces behind this research. Within the last 20 years, the visual spatial abilities needed in science have been included in this research base .

Thurstone (1938) identified spatial ability as a major and separate factor of intelligence. Initially this factor was called spatial relations, however, on further study he separated this factor into two components: spatial relations and spatial visualization. Spatial relations is defined as being able to identify a figure when looking at it from a different perspective. Spatial visualization is a more complex factor and is defined as the ability to rotate multiple parts of a whole figure. Thurstone developed several spatial tests, "Cards" and "Cubes" being two of many. The Form Board test was used by Thurstone to measure spatial visualization.

French (1951) also identified two components of spatial ability: spatial orientation and spatial visualization. Spatial orientation is defined as "the ability to remain unconfused by the varying orientations in which a spatial pattern may be presented" (p.241). Spatial visualization is defined as the ability to manipulate multiple objects in the mind.

French, Ekstrom, and Price (1963), Guilford and Lacey (1947), and Thurstone (1938) all developed spatial tests for measuring the three different components of spatial relations, spatial orientation and spatial visualization. These tests can be identified in the International Directory of Spatial Tests (Eliot & Smith, 1983) and in the Ninth Mental Measurement Yearbook (Mitchell, 1985).

The accuracy and speed with which individuals solve spatial problems is one dependent on the individual's spatial ability. Some students may take a long time to solve a spatial problem, while others take less time. Students who work problems fast may give both correct and incorrect answers. Speed does not correlate positively with accuracy. Timing a visual spatial test may not result in an accurate measurement of the student's visual spatial ability. Therefore, research using timed tests is not necessarily the best indicator of how much visual spatial capability a person has. Because of these individual differences in processing rates, students need to have enough time to process the spatial problem.

Visualization Skills

Two important researchers in the area of visualization and science are Robert McKim and Alan McCormick. McKim (1980) identified several types of visualization skills, starting with simple observation to more complex image synthesis. Some of these operations of visual thinking are: pattern seeking,

visual recall, rotations, orthographic imagination, visual reasoning, and visual synthesis.

Pattern seeking is the ability to find a pattern within an image or dis-embed an image from distracting surroundings. One example is to look at several chemicals according to their luster. By arranging them in order of decreasing shininess, one can see the elements are arranged from left to right on the periodic table. In biology, a student observing microorganisms under a microscope must dis-embed a particular part of the organism from the rest of the organism. In the medical profession, this skill is critical during surgery when doctors must be able to find particular organs as they are surrounded by tissues and other organs.

Visual recall is used when students are asked to examine a picture, graph, or object and later recall it from memory. All the sciences use visual images to convey the relationship between variables in an experiment. Some common examples are the H-R diagram in astronomy, the Pressure/Volume/Temperature graphs in chemistry, and the Krebs cycle and cell structure in biology. Each of these charts or diagrams present information clearly and concisely, whereas the verbal description sometimes takes several pages to do the same. As a result, teachers use these diagrams in science and ask students to recall the information from them.

Rotations involve changing the orientation of an image along any plane or axis. In organic chemistry, the skill of rotation is required for the identification of stereoisomers. Biochemists use this skill when examining viruses in order to determine the active spot on the virus coating.

Looking at an object from another perspective falls under the category of orthographic imagination. This skill is critical for examining how the molecular

structure of a compound relates to its reactivity and the function of specific molecular groups within the compound. Other skills under this category include taking a two dimensional object and converting it to a three dimensional model or vice versa.

Visual reasoning is similar to logical reasoning. In inductive visual reasoning the person is asked to induce how an abstract principle in sequential images relates to a final image. Looking at sequential pictures of concrete objects and predicting what the final picture would be is an example of this skill. An artist uses deductive visual reasoning in taking an abstract idea and making it into a concrete object representing the idea. An excellent example of this is the artist Bev Doolittle, whose camouflage art has an underlying nature conservation theme.

Visual synthesis is the highest step in the hierarchy. It involves the skills of putting together parts of an object or idea to make a whole new and different object or idea. For example, the developer of a new invention uses this skill when pulling together all that is known about the different aspects of the would-be product. In the development of the television, the inventors used information about electromagnetic waves, electrical circuitry, and the transmission/receiving of electromagnetic waves. Without this type synthesis many of our everyday products would not be present.

McCormick (1988) went a step further and developed a hierarchy of visual-spatial skills. He divided these skills into four major categories: visual-spatial perception, visual-spatial memory, logical visual-spatial thinking and creative visual-spatial thinking. All of the operations that McKim (1980) identified are subsets of McCormick's hierarchic model.

Visual spatial perception is defined as the ability to form mental images of observed objects and to observe fine details of objects. This is the simplest of all the skills and is commonly called observation in science. In chemistry, one carefully observes reactions and the property changes that occur. In biology, careful observations led to the main classification schemes used for all plant and animal life. Taking careful and exact observations is one process skill that all chemistry teachers emphasize.

Visual spatial memory allows the storage and retrieval of mental images. It also allows a student to visualize an object when given a description of the object. In chemistry, models are frequently used to represent the atomic/molecular level of chemistry. The students see three dimensional models or two dimensional diagrams and store them in their memory. Later when the teacher discusses the molecule, students can retrieve these images and use them to add functional/physical characteristics to that molecule. A specific example would be when students learn the structure of the alcohols. After learning the three dimensional structure of the alcohol, they then learn about how the structure of the molecule may affect the property of solubility.

Logical visual spatial thinking consists of such skills as pattern finding, interpreting two dimensional representations of two dimensional objects, mental rotations of objects, and looking from a different perspective. The majority of visual operations McKim (1980) identified are clustered in this category. Chemistry texts are full of diagrams that depict the atoms and molecules and their interactions. These are two dimensional images and from this, students must equate those pictures with dynamic particles that cannot be seen, just inferred. The three dimensional molecules that students make are critical to the understanding of the structure/function relationships for these molecules.

The final level of the hierarchy is creative visual spatial thinking where all of the above segments are utilized together to synthesize something new. In chemistry, an application of this phenomenon occurs when scientists construct new models and/or new compounds based on data they have collected. Biological research on virus structures and reactions also relies heavily on the synthesizing ability of the researchers. Currently, the use of the microcomputer and three dimensional imaging programs has allowed research to progress at a much faster rate. Researchers can see the molecule depicted on the screen, rotate it, and look for areas where an antibody can be inserted to turn off the replication of that virus.

Reasoning Ability

There is a large data base of research on reasoning as a part of general intelligence (Piaget, 1960; Thurstone, 1938). Thurstone (1938) identified reasoning as an important factor and included it in his tests. These tests consisted of problems that would identify some sector of reasoning: for example, geometric puzzles, analogies, and series tests. Through this research, two major components of reasoning were identified: a deductive factor and an inductive factor. Deductive reasoning progresses from the general concepts to the specific, and inductive reasoning progresses from the specific concepts to the general.

Piaget, in his study of the developmental growth of children, used reasoning tasks to formally evaluate children. Other researchers have expanded his work (Arlin, 1982; Lawson, 1978; Raven, 1973) with paper and pencil tests. With these tests, the researcher can classify a student's performance into different levels of reasoning ability.

For example, the classifications of reasoning ability resulting from the Arlin Test are low concrete, high concrete, transitional, low formal, and high formal.

Relationship Between Formal Reasoning and Spatial Visualization

A study by Hakstain and Cattell (1974) of the interaction between spatial orientation, spatial visualization and reasoning ability found a greater correlation between spatial visualization and reasoning abilities. Spatial visualization tasks are more complex than spatial orientation tasks. Tasks requiring higher levels of reasoning correlated more strongly with the spatial visualization than spatial orientation tasks. Kail and Pellegrino (1985) also found that reasoning and spatial ability both are similar in that they consist of complex levels.

Subject Matter and Visual Spatial Abilities

Visualization skills are not only important skills needed in doing scientific research, they are also important skills needed for learning of content in subject areas such as architecture, engineering, math, and physics. High correlations between visual spatial abilities and aptitudes in math were found by Fennema and Sherman (1977), Sherman (1980) and Stallings (1979). More recent studies in math have examined the relationship between specific visualization skills, math achievement, and instruction on the visualization skill. Wheatley and Yackel (1990) found that visual spatial abilities are linked to the understanding of geometrical concepts in second grade students. Ben-Chaim, Lappan, and Houang (1988) found that for middle school students who had an instructional visual spatial intervention, spatial visualization skills improved and were retained. The recent report Curriculum and Evaluation Standards for School Mathematics (National Council of Teachers of Mathematics, 1989) included a standard called spatial sense. The same spatial skills necessary for

mathematics achievement as identified by Del Grande (1990) are identical to the skills necessary for greater achievement and understanding in science.

In the area of physics, Peltzer (1988) found that physicists in colleges and universities believe there are four general intellectual factors most important to physics students. They are (a) ability to reason in terms of visual images (visualization), (b) mathematics ability, (c) logic, (d) and problem solving ability. In a study by Palland and Seeber (1984), visual spatial ability was also found to be correlated to achievement in introductory college physics. They examined three specific visual spatial skills: perception, orientation and visualization. After weekly instruction in visual spatial methods, the treatment group consisting of physics students had greater visual spatial skills. This indicates visual spatial skills can be improved with an appropriate instructional intervention.

Historical Importance of Visualization in Science

A specific skill used in all sciences is the ability to visualize models and microorganelles. The ability to visualize is related to how well a person can see or perceive distinct features of an observable object. For example, when a student examines a microorganism under the microscope, he/she must be able to pick out the identifying characteristics of that organism. If it is a paramecium, he/she looks for an elongated slipper shape, central nucleus, and cilia. Likewise, in chemistry, careful observations of macroscopic properties during a chemical reaction are critical to success. Such examples would be the observation of precipitation reactions, where the color and the amount of precipitate are important to the identity and solubility of the chemical. Another important example in chemistry is the ability to take a three-dimensional model of a molecule and visualize how it would look from another viewpoint.

Examining models of molecules from different perspectives leads to a greater understanding of the structure/function relationship.

Scientists often explain their data by use of models (i.e., the atom, electron clouds and DNA). In chemistry students are asked to visualize such models and recall them at a later time. For example, the models of atomic structure and electron structure are applicable here. We draw pictures of electron clouds and their interactions. We then use these pictures to explain how and why bonding between atoms occurs.

Many great inventors and scientists derived their success from their ability to visualize concepts or solutions to a problem. Roe (1952) interviewed 64 prominent scientists, and the majority said they relied heavily on visualization to help them in their research. A well-known example was Albert Einstein. In his book Autobiographical Notes, (Einstein, 1979), he described his thinking as a process where he sees pictures in his mind and manipulates these pictures in order to solve a problem. Another famous scientist/inventor who depended on visualization was the Russian physicist Telsa. His images of parts and whole machines are legendary. He was able to see how machines worked and even would allow them to run in his mind. All this was done by visualizing before the actual models were built. Similarly, Thomas Edison often used mental images that he combined in order to solve the problems he had with devices such as the telegraph. In chemistry, Friedrich Kekule claimed that his discovery of the ring structure of benzene was stimulated by a dream in which he saw a snake biting its tail.

Factors that Affect Chemistry Learning

Seddon, Eniayaju, and Josoh (1984) studied the visual spatial abilities of Nigerian students who had completed their 11th year of schooling. Students

who failed a Rotations pretest were given instruction in the skill. The instructional method was developed to help students visualize three-dimensional rotation of molecules. It focused on using depth cues, shadows, and models. Students who received training showed a significant increase in their ability to visualize the rotation of three-dimensional models of chemicals, thus indicating visual spatial skills can be taught in chemistry.

In chemistry, understanding of the concepts of molecular structure and stereochemistry depends on the visual-spatial abilities of students. Holford and Kempa (1970) found that instruction using stereoscopic presentations improved the visualizing ability of three dimensional relationships in college structural chemistry students. They used programmed instructional booklets that required students to use stereoscopic viewers. Using the stereoscopic viewers contributed positively to the ability to visualize and interpret structures represented by a photograph. This, of course, ties into the structure/function relationship that was mentioned earlier and is so important to chemistry. Hill (1971) found that remediation and instruction in spatial skills improved student achievement in specific stereochemical topics at the college level.

George and Fensham (1973) reported successful teaching strategies in relating three dimensional models, two dimensional drawings, and other written symbols to primary, secondary and tertiary alcohol structures in a college organic chemistry course. In this study the students made drawings of the three dimensional structures, with an emphasis on orientation and perception. Including these instructional techniques increased student comprehension and achievement. Clements and Lean (1981) found that in students who constructed three dimensional models from two dimensional chemical models, comprehension of structure increased.

Baker and Talley (1974) investigated the relationship between achievement scores and visual spatial abilities for college inorganic chemistry students. The exam scores were subgrouped according to Bloom's Taxonomy. They found a strong positive correlation between achievement and visual spatial abilities. Specifically, the scores on the higher levels of subgroup questions (analysis, synthesis and evaluation) showed a positive correlation to visual spatial abilities. Pribly and Bodner (1987) examined the relationship between visual spatial ability and exam scores in college students taking organic chemistry. Students with higher visual spatial skills did better on problem-solving and three dimensional rotation exercises on the exams. The visual spatial skills examined included perception, orientation, and rotation of molecules.

Carter, LaRussa, and Bodner (1987) also examined the visual spatial abilities of general college chemistry students. These abilities were analyzed with regard to exam scores, types of exam questions and gender. The exams were subscored into 35 different categories according to the type of question. Categories included recall, problem solving, and dimensional analysis. An analysis of variance showed that there was a significant correlation between visual spatial abilities and exam total scores and subscores. Thirty-two of the 35 subscores identified by question type (recall, problem solving, etc.) showed significant correlation with regard to high/medium/low visual spatial students. Students who were found to be highly visual had more correct answers on the question types that required more problem solving than students who were classified as low visual spatial. No correlation with gender was found.

Despite the wealth of research focusing on college level chemistry and visual spatial abilities, little research on visualization skills and achievement at

the high school level has been conducted. Also, little research has been done to examine the effectiveness of instructional strategies that use visualization skills in the high school chemistry courses. With these factors in mind, a study focusing on what contributions visualization skills make toward learning of chemistry concepts at the high school level seemed appropriate.

Chemistry learning is also tied to the formal reasoning abilities of students. In an analysis of scientific concepts, Lawson and Renner (1975) identified two major concept categories: concrete and formal. Concrete concepts are learned from direct experience, and formal concepts require the students to go beyond their experiences and draw conclusions based on logic and inferences. Lawson and Renner found that formal concepts could not be learned by concrete operational students. These findings were corroborated by Cantu and Herron (1978) in their study of chemistry students. Marek (1986) and Simpson (1986) also found that concrete operational students could not understand formal concepts. Lawson and Thompson (1988) stated that concrete operational students also have trouble distinguishing between a correct concept and a misconception if the concept is at a formal level. Bitner-Corven (1989) found that for grades 6 through 10 there was little evidence of formal operational reasoning. Haidar and Abraham (1991) found that in a study of the particulate nature of matter, the majority of the 11th grade students were classified as low formal operational. Their research found a significant correlation between students' reasoning ability and scores on concept comprehension tests. Gabel, Samuel, and Hunn (1987) found that 22.8% of the variance in their study was accounted for by students' reasoning ability. Research has shown that the majority of students in chemistry are at the

concrete operational level, whereas understanding of the many abstract concepts presented in chemistry requires a formal reasoning level.

Chemistry Instruction

Current research in chemistry instruction has identified the following general characteristics of traditional chemistry instruction (Herron, 1990): (a) Traditional chemistry instruction stresses facts and not concepts; (b) the instruction does not tie together major concepts within the subject area or between subject areas; (c) the laboratory activities are mainly verification laboratories with few or no discovery laboratory activities; (d) process skills and other skills that would benefit the understanding of students are not taught; (e) teachers emphasize breadth and not depth, often trying to cover an entire chemistry textbook in 1 year. These practices often lead to decreased enrollments and dislike of chemistry at the high school and college levels and are not instructional practices promoted as good chemistry instruction. Good chemistry instruction would include practices that are opposite from the ones stated above.

In good chemistry instruction, three levels of thinking should be addressed: the phenomenological, the symbolic, and the atomic/molecular. The phenomenological level looks at the physical and chemical properties of elements and molecules at the macroscopic level. For example, when we place a piece of copper in a silver nitrate solution, the following macroscopic changes are observed: the copper wire becomes covered with a silver material. After a period of time, the copper appears to have disappeared, and there are numerous silver crystals where the copper was. The solution, which was initially clear and colorless, is now beginning to turn slightly blue, and so on.

Observation skills are very important for understanding at this level. All students should be able to perceive the same reaction.

At the symbolic level, instruction involves using symbols to represent the observations taken earlier. Suppose a chemistry instructor writes on the board the following equation: $\text{Cu} + \text{AgNO}_3 \longrightarrow \text{Ag} + \text{CuNO}_3$. The reaction is described as a single replacement reaction where the copper atoms and silver ions exchange places to form two new substances. At the final atomic/molecular level, a description of the reaction would include the explanation of the reactivity of silver and copper atoms, the importance of the ionic species in the reaction, and the conservation of atoms in a reaction. It is at this level that we use numerous models to explain the observations at the sensory level.

The relative emphasis placed on a particular level of thinking depends upon the individual chemistry instructors and how they were taught chemistry. Chemistry teachers often teach a given concept exclusively at one level. The other levels of instruction are often omitted, or if they are included, the relationship between the concrete and abstract ideas is not explained. For example, traditionally, in the topic of balancing equations the emphasis is on the symbolic level. Little or no attempt is made to merge the three levels of instruction for students (Johnstone, 1993). As a result, students fail to see and understand that the reaction is a collection of particles and this collection is what gives us the characteristic properties we use to describe what is going on--

our observations are at the phenomenological level. When asked to draw diagrams of the atoms and/or molecules and how they interact from a balanced chemical equation most students are unable to do so (Yarroch, 1985). Gabel and Schrader (1987) also found that students come out of chemistry classes able to balance equations without understanding the reactions at the molecular level. Hesse and Anderson (1992) found that in their study of student learning of chemical change, only 1 student out of 11 was able to explain the phenomenological level observed by utilizing the atomic-molecular explanation.

As we move from the phenomenological to the atomic/molecular level of chemistry, our thinking moves from the concrete to the abstract. The cognitive developmental level of students in high school chemistry may range from a concrete operational to a formal operational level of reasoning (Herron, 1990). Comprehension of chemistry concepts may require a higher level of thinking; thus, the student needs to be able to reason at a formal level.

In examining the three levels of chemistry instruction, the ability to visualize is required more as one moves from the concrete (phenomenological) to the abstract (atomic/molecular) level. The phenomenological level requires students to have a visual memory of what occurs during the reaction. For example, in adding a metal to an acid, students must remember that fizzing occurred, the test tube got hot, and the metal disappeared or changed color. The abstract level often requires students to be able to visualize the models that

are used as explanations. They are asked to take apart whole molecules and put them back together in a different arrangement and be able to conserve the parts at the same time. Because chemistry relies so heavily on visual spatial skills, visual spatial abilities should be important for success in chemistry.

Summary

Chemistry education researchers have sought to understand the processes and abilities that affect chemistry achievement. Through a series of aptitude tests researchers have identified student development in a variety of areas. One such area is spatial ability. Atomic/molecular concepts are highly abstract and require students to visualize microscopic particles not normally seen. The student's ability to visualize these models used for explanations play an important role in student achievement.

Another area of importance to researchers is the reasoning level of chemistry students. If students are able to comprehend the formal scientific concepts as defined by Lawson and Renner (1975), they must be at the formal reasoning level. Hairdar and Abraham (1991) found a significant relationship between students' reasoning ability and concept comprehension scores.

Chemistry instruction often focuses on using algorithms to learn chemical concepts. There is a need to make relevant links between the phenomena we see in laboratories, the symbolic means chemists use to explain these phenomena and the atomic/molecular explanations of the chemistry concept. All of the above variables are important factors in chemistry comprehension.

CHAPTER 3 RESEARCH DESIGN AND IMPLEMENTATION

Overview

This study was designed to examine the visual spatial and formal reasoning performance of students and how these two factors affect the comprehension of the abstract concept of atoms and molecules. The context for the investigation is the study of the chemical topics of conservation of mass and balancing equations. It was hypothesized that the use of visual modeling by students would increase their conceptual understanding of these topics. It was further hypothesized that there would be a relationship between student performance on visual spatial tasks and their achievement in chemistry.

In Chapter 3 the study sample, the curriculum, the spatial evaluation instruments used to measure the different visual spatial tasks, the formal reasoning test and the instrument used to measure chemistry achievement are described. The data collection and statistical data analysis procedures used are also described.

Study Sample

The hypotheses were tested with students from high schools located in the Desoto County School System and the Hardee County School Systems in Florida. All participants were in the 11th or 12th grade and were taking chemistry. Students could not be randomly selected for the investigation, and intact chemistry classes were used. Traditionally, the prerequisites for taking chemistry are previous course work in biology and algebra. These

requirements eliminate students with special learning disabilities from the study. The socioeconomic make-up of the school systems involved include students from low to high socioeconomic levels, with the majority of the students coming from low- to middle-class families.

Three teachers were chosen to participate in this study on the basis of their teaching experience and willingness to participate. Teacher A had 22 years of teaching experience; Teacher B had 16 years teaching experience; and Teacher C had 16 years teaching experience. Beginning teachers were not selected because of their lack of teaching experience and their lack of familiarity with different teaching methods. The teachers in this study were two males and one female.

Curriculum

The existing or the modified version of curriculum covered the important and traditional topics of conservation of mass and balancing chemical equations. It consisted of a 15-day curriculum covering the topics of conservation of mass, types of chemical equations, balancing chemical equations and laboratory applications for each of the topics. Each of the teachers was instructed on the modified curriculum for a period of 2 hours by the researcher. The curriculum was laid out with the content, worksheets, and time line to be spent on each segment of the topic. Appendix A contains the curriculum guide with the outline of the content topics and timeline. Both the control and experimental groups covered the same chemistry content. The difference between the two treatments lies in the use of visual models to promote the comprehension of the abstract concept of atoms and molecules. Validation of the content was done by sending the curriculum to a chemistry professor long interested in curriculum and instructional issues, and asking for

evaluation. Dr. Robert Bernoff, University of Pennsylvania, checked the curriculum guide for content correctness and instructional techniques. Two local high school chemistry instructors also examined the curriculum for continuity and correctness by comparing it to textbook presentations of the material.

Evaluation Instruments

Students were evaluated to determine their visual spatial ability, formal reasoning ability, and prior chemistry knowledge. Three independent measures representing different aspects of visual spatial ability were administered using three different paper and pencil tests. A paper and pencil test was used to determine formal reasoning ability and chemistry knowledge. A description of each of these tests follows.

Visual Spatial Tests

Card Rotation Test

The Card Rotation Test is a commonly used test for visual spatial ability. It was designed by Thurstone (1938) while he was investigating primary mental abilities. It was included in the Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, Harman, & Derman, 1976). The Kit was initially developed by French (1954) then revised by French, Ekstrom, and Price (1963). The spatial orientation and spatial visualization factors from this Kit were areas of interest in this investigation.

The purpose of the Card Rotation test is to measure a student's ability to recognize difference, when the figure's orientation is changed. The test measures a student's ability to mentally rotate an image in order to check for similarities.

The test contains 14 problems. Each problem has a shape followed by

eight drawings of that same shape. The drawings have been rotated from the original orientation, flipped over or flipped and rotated from the original orientation. For each of the eight drawings the student must decide if the original drawing and it are same orientation or flipped orientation. Students mark a + if they are the same and a - if they are flipped. A sample drawing is shown in Figure 3-1.

Although the original test was supposed to be a timed test, this investigation focused on overall visual spatial ability rather than speed of visualization. Therefore, the test was not timed and students were allowed to work at their own pace. This test was selected due to the similar skills needed in science for rotating molecules in space in the study of stereoisomers.



Figure 3-1. Sample Card Rotation Problem

Form Board

The first Form Board Test was developed in 1930 by Paterson, Elliott, Anderson, Toops, and Heidbreder in a study on mechanical ability. The test was revised and included in the Kit of Reference Tests for Cognitive Factors. It has undergone several revisions and is commonly used to test spatial visualization. The test used in this study was taken from the Kit of Reference Tests for Cognitive Factors. The purpose of the test is to measure a student's ability to identify the individual pieces that fit together to make up a whole figure.

Students must mentally execute several operations in trying to match pieces against the whole. The pieces must be grouped in various combinations and some of the pieces must be rotated and then combined.

The test consists of a whole figure with several pieces that may fit together to make the figure shown below. The student must choose from two to five of these individual pieces to complete the figure. An example is in Figure 3-2. The test contains 24 items. This test was selected because it measures the more complex ability to manipulate two-dimensional figures composed of individual pieces. Again the test was not timed as the investigation was not looking for speed but overall ability. This test was selected due to the similar process used in the synthesis of molecules from atoms in chemical reactions.



Figure 3-2. Sample Form Board Problem

Hidden Figures Test

The Hidden Figures Test was taken from the Longitudinal School Mathematics Study. It was adapted from the Hidden Figures Test, a part of the Kit of Reference Tests for Cognitive Factors. The task is one of disembedding a simple figure from a complex pattern that has been organized to obscure or embed the simple figure. The test is a variation of the Group Embedded Figure Test, which measures field dependence and independence, a component of spatial ability.

The test consists of 16 complex patterns. Beside each pattern five simple shapes are drawn. The student must identify which of the five simple shapes are a part of the complex pattern. Figure 3-3 below shows a sample from this test.



Figure 3-3. Sample Hidden Figure Problem

This test was chosen because of its similarity to the skill scientists must use when looking for components in a large molecule that are the basis for chemical interactions. This relates to the structure/function issue in chemistry.

Content Test

The content test was developed according to educational evaluation guidelines. Initially, the times need to cover each content topic were tallied. The percentage of time spent per topic was derived from this information. For example, a total of 120 minutes of 700 total instructional minutes was spent on visualization or modeling of the concepts. Thus, 17% of instructional time was spent on visualization. For a 50- question test, 17%, or nine questions, consisted of visualization items. This method was used for all topics covered in the curriculum. The corresponding numbers of tests items were then written for each topic. A 50 item test was chosen due to the limitation of available class time. Presently, most class periods run between 50 and 55 minutes.

The content test was further validated by sending it to an expert in the field for review. Dr. Robert Bernoff, Chemistry Education Professor, University

of Pennsylvania, worked with the investigator on wording and degree of difficulty. Another step in validation was done by checking to see that each test question corresponded to the appropriate topic. One science professor and three chemistry teachers coded the questions as to topics; (e.g., conservation of mass, energy relationships, types of reactions, balancing equations). There was 98% agreement between the professor and the investigator and 99% agreement between the teachers and the investigator. Changes were made on the questions that were not in total agreement.

The test was then given to 60 students in a local high school chemistry class. Two weeks later the test was given again. Test-retest reliabilities were determined for the tests. No significant differences were found between the scores on the pretest and scores on the posttest. Appendix B contains a copy of the content test.

Formal Reasoning Test

Numerous research studies have shown that reasoning is an integral part of intellectual performance (Piaget, 1960; Thurstone, 1938). Piaget and Inhelder(1958) developed individual tests that assessed formal reasoning. Several paper and pencil tests have been created to measure reasoning (Arlin, 1982; Lawson, 1978; Raven, 1973) based on these tests by Piaget and Inhelder. These paper and pencil tests were developed so that large numbers of students could be assessed in a minimum amount of time. Arlin (1982) developed a paper and pencil test based on the developmental theory of Piaget and Inhelder. According to Piaget (1958), students pass through four distinct stages in their development from childhood to adult. These four stages of intellectual development are the sensorimotor stage, from birth to age 2; pre-operational stage, from age 2 to age 7; concrete operational, from age 7 to age

11; and formal operational, from age 11 on through adulthood. These time frames are to be used only as a guide and are not absolute. Examining high school students shows that all stages of development may be present in a given sample.

The Arlin Test of Formal Reasoning is a 32-item test. The questions are in a multiple-choice format. Test items use math and science concepts as a base for the questions. The test is untimed, taking approximately 30-45 minutes. The test assesses the students according to one of five different cognitive levels: low concrete, high concrete, transitional, low formal and high formal. Studies (Arter & Salmon, 1987; Fakouri, 1985; Santmire, 1985) have shown the instrument to be valid and reliable for assessing the reasoning ability of groups.

Data Collection

Data were collected in the following manner. On day 1, the Pretest for Chemistry content and the Card Rotation test were given by all three teachers. On day 2, the Hidden Figures test and the Form Board test were administered. The Formal Reasoning Test was given on day 3. All tests were given in this same order to limit any internal validity threat. The Chemistry content test was given first. Otherwise, practice with visual models in the visualization tests might have confounded the content results.

Each teacher read the test instructions to the students. The teachers went through a sample problem with the students and answered any questions prior to administering the tests. None of the tests were timed.

Day 4 began the two-week instructional package. The teachers followed the curriculum guide daily. Each teacher kept notes and comments during the instructional period. Journal entries covered time schedules, problems

encountered, and any other ideas they might have about the curriculum or instruction. During the instructional period, two days were videotaped for each group. The focus of the videotapes was on how students interacted with the manipulatives and on verification that the instructors were following the lesson plans correctly.

The difference between the experimental and control curriculum package was in the use of hands-on three-dimensional manipulatives and two-dimensional models to represent atoms and molecules. Traditionally, chemistry instruction does not include these manipulatives in the study of conservation of mass and balancing equations. The experimental group worked with the hands-on manipulatives and two-dimensional models, while the control groups received traditional instruction. After the entire curriculum had been implemented, all students took a post-content test.

Approximately 2 weeks after the unit, I interviewed two students from each class, for a total of 12 students, with a semi-structured interview protocol. The purpose of the interview was to identify any misconceptions and/or non-learning that had taken place. One student at a time was interviewed in a room adjacent to the classroom. Students were given a set of magnets and their use was explained. Then the students were given a set of chemical equations to balance. Instructions were given to the students and they were asked to talk aloud while they were working the problem. I recorded all student comments and how they used the magnets. After they completed each question, I asked them to explain the reasoning behind any errors I noted when they were solving the problem. Further student comments were recorded from this information. Appendix C contains the student interview sheet and protocol.

A pilot version of this study was conducted on 60 students in Alachua

County in the spring of 1993. The students completed all three visualization tests and were given the content test. They were also instructed using the curriculum guide. This was done to validate the curriculum package and to examine the difficulty level of the visualization tests. The pilot study showed that the students in the experimental group had a greater understanding of how atoms and molecules interact and, after using the manipulatives for a period of time, became very proficient in discussing chemical reactions in terms of atoms and molecules. The pilot study provided justification for further investigation using a larger sample.

Data Analysis

The SAS general linear model was the statistical procedure used in this investigation. Use of this model allows the examination of several independent variables to determine if differences in posttest content scores are due to prior visualization skills, reasoning ability, or treatment effect.

The three visualization scores (Card Rotation, Form Boards and Hidden Figures) were treated as interval scores as were the content tests. The formal reasoning test was considered a continuous score. This procedure allowed the following questions to be answered:

1. Is the difference in content performance related to instructional method?
2. Is the difference in content performance related to visualization ability?
3. Is the difference in content performance related to reasoning ability?
4. Is the difference in content performance related to the combined effect of visualization, instructional method or reasoning ability?

Limitations

This section contains a description of the external threats to validity. Certain threats could not be avoided, but every effort was taken to minimize these effects.

To make sure that there was minimal teacher effect in this study, a concise script of the curriculum was provided and explained by the investigator. Journal keeping and video taping were also be done to provide further validation that the curriculum was followed as directed.

A second limitation relates to the nature of the subject area. Students taking this course normally exhibit a higher ability level in math and problem solving than the average 11th or 12th grade. Several types of students may have been scheduled into a particular class due to other scheduling conflicts. For example, band is only offered during one period of the day, and honors classes are only offered during one period. When choosing which groups to use as control and experimental, an effort was made to ensure that the overall groups were not significantly different.

CHAPTER 4 RESULTS

The purpose of this study was to examine how achievement in chemistry is affected by instruction using visual modeling of atoms and molecules. Other factors examined in the study were the effects of formal reasoning skills and visualization skills on chemistry achievement. The students took a formal reasoning test, three different visualization tests, and pre and post content tests. The content test consisted of two parts, each part relating to the instructional method used. There were two instructional methods used in teaching chemistry concepts. The treatment method used a hands-on approach with three dimensional models to represent the chemical concepts. For example, a model of water would be . Traditional chemistry instruction uses chemical symbols (e.g., Na, NaOH) to represent the concepts presented. Water would be represented by H₂O, not the model above. Part one of the test had concept questions using only the symbols. Part 2 had questions requiring visualization and a visual means for conveying the knowledge.

Mediating variables in the study were the precontent test, a test of formal reasoning, and three different visualization tests. Results of the analysis of effects of these variables are presented in the next sections. The correlations between all of the variables are given in Appendix D. The design of the study appears in Figure 4-1.

<u>Chemistry Instruction</u>	<u>Mediating Variables</u>	<u>Code</u>	<u>Outcome</u>
Treatment & Control test & Groups Interviews	Precontent test	Precon	Postcontent
	Formal reasoning test	ATFR	Selected
	Card Rotation test	Card	(Postcon)
	Form Board test	Form	
	Hidden Figure test	Hidden	

Figure 4-1. Layout of the Study.

The Relationship Between Chemistry Achievement and Instruction

The first analysis assessed the relationship between achievement and instruction in chemistry. The conceptual hypothesis stated that the post test achievement test for the experimental group would be greater than for the control group. The instruction with the control group was modeled after the traditional chemistry instruction. Concepts were developed using only chemical symbols and words. Laboratory activities were done to verify these concepts. The experimental group differed in that an emphasis was placed on three-dimensional modeling depicting the underlying atomic/molecular structure. Students manipulated models for both the laboratory and conceptual components of the curriculum. The question of whether treatment affected achievement was evaluated using a t-test on both control and experimental group results.

To determine whether treatment and control groups were equivalent on prior knowledge, a precontent test was administered prior to treatment. The test had two parts and an analysis was done for total scores as well as each individual part. Analysis of a t-test ($\alpha = 0.05$) of precontent scores indicated there was no significant difference between the control and

experimental groups on the total pretest scores as well as for each part of the test. Both groups showed equivalent prior knowledge on this topic. Also important to note is that neither group was able to explain the abstract concept of atoms and molecules, a topic that is introduced and used for explanations throughout chemistry. It is also interesting to note that the concept of atoms and molecules is introduced and explained in most chemistry textbooks in Chapter 2, whereas Conservation of Mass and Balancing Equations comes much later in the curriculum. The students had been exposed to this concept previously.

A comparison of the two groups using a Tukey-Kramer HSD analysis ($\alpha = 0.05$) showed there was a significant difference in performance between the control and experimental groups on part 2 (visual representations) and total score on the post content test. There was no significant difference in the part 1 (traditional content and algorithms) posttest scores between the experimental and control groups. Tables 4-2 and 4-3 show the means and numbers per group for scores on part 1, part 2 and total of both the pretest and posttest.

Table 4-2

Means of the Total Pretest Scores (Max. pts. = 50), Part 1 Pretest Scores (Max. pts. = 35) and Part 2 Pretest Scores (Max. pts. = 15) by Treatment

Pretest Scores	Total	n	StdErr	Part 1	n	StdErr	Part 2	n	StdErr
Exp. Group	5.51	64	.47	5.14	64	.41	0.38	64	.12
Control Group	6.13	63	.48	5.75	63	.42	0.38	63	.12
Significance	prob> t = .3651			prob> t = .3051			prob> t = .9718		

Table 4-3

Means of the Posttest Achievement Scores, Part 1 Scores and Part 2 Scores by Treatment

Posttest Scores	Total	n	StdErr	Part 1	n	StdErr	Part 2	n	StdErr
Exp. Group	26.83	61	1.37	21.89	61	.98	4.95	61	.53
Control Group	22.61	54	1.46	19.91	54	1.04	2.70	54	.56
Significance	prob> t = .0373			prob> t = .1683			prob> t = .0044		

The results of these tests indicate that instruction using a visual technique increased chemistry achievement on the topics of atoms, molecules, and balancing equations. The scores on part 2 of the content posttest indicated that the students in the visual instruction group had a greater understanding of the abstract concepts of atoms and molecules and their role in the chemical concept of conservation of mass.

Increased chemistry comprehension was further shown qualitatively in interviews with randomly selected students after the unit was completed. Two students from each classroom were randomly chosen to participate in a structured interview. They were interviewed individually. The interview protocol appears in Appendix C. The students were asked to balance a chemical word equation using the magnets. They were then asked to balance an equation already written in chemical symbols. Finally, they were asked to demonstrate the concept of conservation of mass on two already balanced chemical equations again using the magnets. The students were asked to explain what they were doing as they balanced the equations and to describe the particles involved in the chemical equations.

Students from both the control and experimental classes could

successfully balance the equations when they were already given in symbolic chemical form. All but one student could do this, indicating that they had learned the algorithm for balancing equations. That is, they balanced the equation using the symbols and count for equal numbers on both side. However, when asked to write a balanced equation from word form, the students could not always do it. They were confused about how to write particular elements and compounds. For example, iron(III) oxide was written as Fe_3O_2 or FeO , but not Fe_2O_3 , the correct formula. If students do not understand how charges are used to give the combining ratios that make up the compound, such errors would be made in answering the questions. This error is significant in that it shows students do not understand how atoms combine to form compounds. Also when asked to use the magnets to represent the particles in the balanced equation, all the students from the control class had the most difficulty. These students commented to me that they "really did not understand atoms or molecules" or "I can balance equations but I don't know what the difference is between an atom or molecule." Three of the students incorrectly named the particles. Atoms in the balanced equations were called molecules and molecules were called atoms in many of their explanations. Only one of the students had no difficulty balancing an equation and explaining the difference between atoms and molecules with relation to what he did. He used the magnets in his explanation and in checking to see that the equations were balanced. He was from the experimental group.

These results indicate that the topic of balancing chemical equations is complex and student comprehension may require more than one time learning the topic. The ACS textbook CHEMCOM addresses this issue. One of ACS's

underlying hypothesis is that it takes multiple examples for student comprehension. Therefore, their textbook may introduce a topic in one chapter and several chapters after that will have applications using this concept to reinforce student learning. Evaluation of this process and textbook is ongoing.

Relationship Between Chemistry Achievement and Formal Reasoning

In order to examine the relationship between chemistry achievement and formal reasoning, two analyses were done, using the total group of subjects to determine whether formal reasoning (ATFR score) affected chemistry achievement. First, the scores of each student were transformed into an ordinal scale indicating their level of performance: concrete, high concrete, transitional, low formal and high formal. Tables 4-4A and 4-4B show the number of students in each group, the scoring scales, and codes for this information.

Table 4-4A

Level of Formal Reasoning, ATFR Scores and Resulting Codes

Level of Performance	ATFR Score	Code
Concrete	0-7	1
High Concrete	7-14	2
Transitional	15-17	3
Low Formal	18-24	4
High Formal	24-32	5

The breakdown of the number of students in each of the five different levels (concrete to formal) is given in the Table 4-4B. Both the experimental and control groups had a similar distribution of students in the high concrete and transitional level. However at the extremes of the formal reasoning scale, the experimental group had a greater number of low concrete, low formal and

high formal level students. Even though each group was randomly assigned, students were not evenly distributed in each formal reasoning level.

Table 4-4B

Total number of students in each reasoning level and per experimental and control group

	Low Concrete	High Concrete	Transitional	Low Formal	High Formal
Total number of Students	5	43	23	15	7
Experimental Group	4	21	12	10	7
Control Group	1	22	11	5	0

In the second analysis, the scores were treated as interval data and a general linear model was run. The null hypothesis follows:

H_0 : There is no significant difference in achievement resulting from students' formal reasoning skills.

The level of significance for rejecting the null hypothesis was $\alpha = 0.05$. The Tukey-Kramer HSD test was used to compare the means on posttest scores according to the ranking on the AFTR test. The test results appear in Appendix E. Table 4-5 shows the mean results of post test scores according to their placement in the AFTR group.

Results show that there was a significant difference in Part 1 of the posttest content scores for the following groups: post test scores for Group 4 and 2 only. Part 2 of the content test shows a significant difference between the

following groups: Group 4 and 3, Group 4 and 2. The greatest significant difference existed between Group 4 and 2. The analysis for the total posttest score indicates a significant difference on achievement between Group 4 and 2 only. Appendix F contains this analysis and graph. This information is consistent with the findings of Haidar and Abraham (1991) and Gabel, Samuel, and Hunn (1987). Their studies found that students at a higher formal reasoning level performed better than students at a concrete level.

Table 4-5

Table of Posttest Scores for Formal Reasoning Groups of Total Group

Means of Posttest Score	Part 1	Part 2	Total	n
High Formal (Group 5)	20.43	5.71	26.14	7
Low Formal (Group 4)	26.00	9.57	35.57	14
Transitional (Group 3)	24.26	4.95	29.21	19
High Concrete (Group 2)	19.38	2.25	21.62	40
Low Concrete (Group 1)	18.40	4.00	22.40	5

An ANOVA on the total posttest score (both content and visualization) and formal reasoning scores indicated that there was a significant relationship between chemistry achievement and ATFR. Chemistry content requires students to comprehend concepts that are often abstract. Therefore, it seems reasonable that students who have a higher level of formal reasoning, dealing with abstract ideas, would have higher achievement in chemistry. This is consistent with research by Marek (1986) and Simpson (1986). The results are shown in Table 4-6.

An analysis was run examining these two effects on each part of the posttest, part 1 and part 2. Part 1 of the test measures traditional content, and

part 2 uses a more visual means for students to explain the ideas. The results are shown in Tables 4-6A and 4-6B.

The R^2 of 0.23 indicates that approximately 23% of the variance in part 1 posttest scores is due to the AFTR scores and precontent scores. Approximately 29% of the variance in part 2 posttest scores is due to the AFTR (formal reasoning) scores and precontent scores. Both parts of the posttest are significantly related to the formal reasoning test. The analysis of interactions between formal reasoning and the type of instruction did not show any significant relationships.

Table 4-6

Analysis of variance between Total posttest score, ATFR scores and pretest scores.

Rsquare		0.28		
Root Mean Square Error		9.14		
Observations		111		
Source	DF	Sum of Squares	F Ratio	Prob>F
Atfr	1	3019.16	36.15	0.0000
Precont	1	450.34	5.39	0.0221

Table 4-6A

Analysis of variance between Part 1 posttest score and ATFR scores

Rsquare		0.23		
Root Mean Square Error		6.63		
Observations		111		
Source	DF	Sum of Squares	F Ratio	Prob>F
Atfr	1	1022.21	23.24	0.0000
Precont	1	333.73	7.59	0.0069

Table 4-6B

The relationship between Part 2 posttest score and ATFR scores

Rsquare		0.29		
Root Mean Square Error		3.67		
Observations		111		
Source	DF	Sum of Squares	F Ratio	Prob>F
Atfr	1	527.83	38.51	0.0000
Precont	1	8.71	0.63	0.4269

Relationship Between Chemistry Achievement and Visualization Skills

In the study, an attempt was made to examine whether particular visualization skills were important in chemistry achievement and specifically if treatment favored one of these. A review of each of these tests and how they relate to chemistry follows. One skill as measured by the Card Rotation test is the ability to rotate objects mentally. In chemistry this skill is necessary when discussing such topics as molecules, their three dimensional structure, and bonding orientation. Students need to visualize the three dimensional geometry in order to understand how reactions may occur.

A second skill, Hidden Figure identification, was also assessed. In this test students are required to find a shape embedded in a figure. In chemistry, this is useful in the area of medical research, where imaging of molecules and parts of molecules is necessary for developing antibodies. In high school chemistry, it is important in identifying the various polyatomic ions that make up a particular compound. Identification of these ions allows a student to better understand solubilities.

The third skill measured by the Form Board test, requires students to take parts of a shape and put them together to make a whole object. Here

orientation, size, and shape are important. Students must be able to not only rotate objects mentally, but also put them together into to form a particular shape. Again, a chemistry student would use this skill in putting the various monoatomic and polyatomic ions together to form the chemical compounds. The geometry or structure of the compound better explains how they react.

Because chemistry uses many different models and diagrams, one would assume that students who have a greater ability to visualize would have greater chemistry achievement. If they do not have better achievement then there is no factor.

The statistics in this section are used to examine the following hypothesis:

H_0 : There is no significant relationship between students' scores on the three visualization tests and chemistry achievement.

The following tables, Table 4-7 through 4-9, show the statistics for determining a relationship between chemistry achievement and each individual test. The final table, Table 4-8, indicates the full model statistical analysis. The value of R^2 was higher for the Form Figures test than for Card Rotation and Hidden Figures tests. This indicates a greater variance in the posttests was due to this variable.

Table 4-7

General Linear Model for the Form Board Test and Total Posttest Score

Rsquare = 0.16				
Source	DF	SS	Mean Square	F Ratio
Model	1	2121.86	2121.86	20.69
Error	110	11279.13	102.54	Prob>F
Total Error	111	13400.99		0.0000

Table 4-8

General Linear Model for the Hidden Figures Test and Total Posttest Score

Rsquare = 0.14				
Source	DF	SS	Mean Square	F Ratio
Model	1	1882.17	1882.17	17.68
Error	106	11282.75	106.44	Prob>F
Total Error	107	13164.92		0.0001

Table 4-9

General Linear Model for the Card Rotation Test and Total Posttest Score

Rsquare = 0.05				
Source	DF	SS	Mean Square	F Ratio
Model	1	618.23	618.23	5.28
Error	108	12635.62	116.99	Prob>F
Total Error	109	13253.86		0.0234

The Hidden Figures, Form Board and Card Rotation visualization tests show that there is a significant relationship between posttest achievement scores and visual spatial ability as measured by these tests individually. Therefore, the null hypothesis is rejected. Table 4-10 shows the general linear model for all the variables. Again, the GLM shows that there is a significant relationship with the Hidden Figures test and Form Board. Card Rotation test is not significantly related.

Table 4-10

General Linear Model for the Whole Model and Posttest Score

RSquare = 0.26					
Source	DF	SS	Mean Square	F Ratio	Prob>F
Model	3	3401.00	113.67	11.88	0.0000
Error	102	9731.84	95.41		
Total Error	105	13132.84			
Form	1	1110.97		11.64	0.0009
Hidden	1	1222.32		12.81	0.0005
CardRot	1	89.32		0.936	0.3356

The posttest content test was then divided into its subsections (Parts 1 and 2) and both individual tests and whole model tests for both parts were run. Test results for part 1 of the posttest (content) were from tables in Appendix G: Hidden - Prob>F = 0.0027, Form Board Test - Prob>F = 0.0001; CardRot - Prob>F = 0.0602. The whole model prob>F = 0.001. Test results for part 2 of the posttest (visualization) were from tables in Appendix H: Hidden - Prob>F = 0.0000, Form Board Test - Prob>F = 0.0000; CardRot - Prob>F = 0.0164. Whole model prob>F = 0.0000. Again, there was a significant relationship between each individual test and the posttest subsections.

Appendix I shows the data analysis using the general linear model for all visualization tests and part 1 and part 2 of the posttest. Again for each individual part both the Hidden Figures and Form Board tests were significantly related. The Card Rotation test was not.

If visualization and formal reasoning affect chemistry achievement, then the treatment emphasis on visual representation should give higher post test scores. Analyses of the interaction of group and each individual

visualization test showed no interaction effect between group and form board test, hidden figures test, and card rotation test.

A final analysis was done to include precontent scores along with the three visualization scores as independent variables. The Form Board test, Hidden Figures Test and Precontent scores all were significantly related to the posttest content scores. The Card Rotation Test was not significantly related to the posttest scores in any of these whole model tests.

The visualization scores were converted to percentages and added to give a new variable called total percent visualization. Analysis was done using this variable and the posttest scores for each instructional group, traditional and visual. For the group receiving traditional instruction, 13% of the variance on their achievement scores could be explained by their visualization scores, whereas for the experimental group, 26% of the variance on the achievement scores could be explained by their visualization scores.

The total visualization score was divided into high, medium, and low scores according to the quartile rankings. Low was classified as the lower 25% on the total score. Medium was classified as from 25% to 75%. High scores were above 75% of the total score. Numerically, low scores were classified as below 192 out of 300. Medium scores were scores between 192 and 252 out of 300. High visualization scores were ones above 252 out of 300. On examining the achievement scores of the two instructional groups, despite instructional type, the students with low visualization skills do not perform well on this test. However, for students classified as medium or high visualizers the method of instruction increased their achievement on the content test. Instruction seemed to have the greatest effect on the students who had medium visualization skills.

The Relationship Between Chemistry Achievement, Visualization,
Formal Reasoning and Instructional Method

A test was conducted to examine the relationship between the posttest scores of achievement and the independent variables of formal reasoning score, form board test, hidden figures test, card rotation test, and precontent score. The results show a significant relationship between the formal reasoning test, hidden figure and precontent scores and the posttest content scores. The form board test and the card rotation test did not show a significant relationship. Thus, the precontent scores, formal reasoning scores, and hidden figures test scores can be used to predict the posttest achievement scores. Table 4-11 below gives this information.

Table 4-11

Full Model Analysis for all Variables

Rsquare = .41					
Source	DF	SS	Mean Square	F Ratio	Prob>F
Model	5	4983.91	996.78	13.25	0.0000
Error	98	7296.52	75.22		
Total Error	103	12280.43			
Precontent	1	607.21		8.072	0.0055
Atfr	1	942.97		12.53	0.0006
Form	1	113.27		1.509	0.2227
Hidden	1	1120.31		14.89	0.0002
CardRot	1	51.72		0.688	0.4090

Based on the above data, the card rotation test and form board test were dropped as factors and the analysis was run again both to check the significance level and to look for any interactions. There were no significant treatment interactions with the hidden figures test, precontent test and formal

reasoning score. The R Square for the model without the Card Rotation test and Form Board test scores was 0.39 indicating that the two variables dropped from the analysis were not providing much variance to the full model. In summary, formal reasoning and one type of visualization skill as measured by the Hidden Figures test are significantly related to the posttest content test on the topic of balancing of equations and conservation of mass.

A final ANCOVA was run to analyze the effect of precontent, teacher, hidden figure score, formal reasoning score, and group on the posttest content score. Both formal reasoning and precontent scores were significantly related to achievement. Neither visualization nor type of instruction, as indicated by the hidden figure score, was found to be significant in this analysis. The chemistry achievement scores for one teacher was significantly higher than the other two teachers. These results may indicate that the teachers either did not completely follow the curriculum guide as they stated or they maintained their teaching styles despite the desire to change.

Summary

The following null hypotheses stated in this study regarding the relationship between chemistry achievement and type of instruction, formal reasoning skills, and visualization skills were rejected:

1. There is no significant difference in achievement resulting from different instructional methods.
2. There is no significant difference in achievement resulting from their visualization skills.
3. There is no significant difference in achievement resulting from the students reasoning ability.

4. There is no significant difference in achievement resulting from the combined effect of visualization, instructional method or reasoning ability.

Discussion of these results and their implications follows in Chapter 5.

CHAPTER 5 SUMMARY, CONCLUSIONS AND IMPLICATIONS

Chapter 5 is divided into four main sections. The first section reviews the objectives of the study. The second section summarizes the results from Chapter 4. The third section discusses the conclusions from these results and the fourth section examines the implications for future research and how these implications could affect curriculum and instruction.

Review of the Study

This study examined the effect of instruction using visual modeling of atoms and molecules on achievement in chemistry. Other factors examined in the study were the effects of formal reasoning skills and visualization skills on chemistry achievement. The students took a formal reasoning test, three different visualization tests, and pre- and post-content tests. The content test consisted of two parts, each part relating to the instructional method used. The treatment method used a hands-on approach with three dimensional models to represent the chemical concepts. For example, a model of water would be . Traditional chemistry instruction uses chemical symbols, (e.g., Na, NaOH) to represent the concepts presented. Water would be represented by H₂O, not the model above. Part one of the test had concept questions using only symbols. Part 2 had questions requiring visualization and a visual means for conveying the knowledge. Mediating variables in the study were the precontent test, a test of formal reasoning, and three different visualization tests.

The study was conducted in three Florida high schools. One hundred and eleven students and three instructors, one from each school, participated in the study. The students were taking chemistry. Each teacher had one control and one experimental study group, for a total of six chemistry classes. The students were in grades 11 and 12 in rural high schools with equivalent socioeconomic backgrounds. In each case, the chemistry classes of each teacher were randomly assigned to the control and experimental group.

The students took a precontent test to determine whether the classes were equivalent in chemistry knowledge at the start of the investigation. Statistical analyses were done to determine if there was a relationship between the chemistry achievement after instruction and each mediating variable. The mediating variables were the precontent test score, the three spatial tests, and a formal reasoning test. The interaction of these variables and chemistry achievement was also evaluated. It was hypothesized that a strongly visual treatment of chemistry content would improve chemistry comprehension on a defined set of topics. The study also investigated related questions, namely, the extent to which visualization skills as measured by the Hidden Figures Test and Formal Reasoning affected achievement outcomes.

Summary of the Results

It was hypothesized that instruction using three dimensional models would enhance the comprehension of atoms, molecules and balancing equations. Students who received this instruction were expected to have greater comprehension than students who did not receive the instruction. It was also hypothesized that students who had better visualization skills would have a higher achievement on the content. Visualization skills are a critical part of chemistry, from observation skills to manipulating two dimensional and three

dimensional particles. Because this topic covers material that is abstract and requires a higher level of formal reasoning, it was hypothesized that students with a higher formal reasoning skill would have higher achievement on the content. The final analysis examined the effect of all the variables on chemistry achievement.

The study sought to answer four questions related to chemistry achievement at the high school level. The questions are stated below.

1. Is there a difference in content performance related to instructional method?
2. Is there a difference in content performance related to visualization ability?
3. Is there a difference in content performance related to reasoning ability?
4. Is there a difference in content performance related to the combined effect of visualization, instructional method, or reasoning ability?

The first three questions examine chemistry achievement on the posttest measure and three independent variables of visualization ability, instructional method and reasoning ability. The fourth question examined chemistry achievement in terms of an interaction of any or all the the variables.

From the analyses, the following conclusions were drawn.

1. Given the same conceptual content, students in the experimental group using the hands-on visual models had a significantly higher post test score on the content achievement measured than did the control group. Comprehension of the abstract concepts of atoms and molecules was enhanced by using this method of instruction.

Part 2 of the post content test utilized a visual means to examine student comprehension of the atomic/molecular level of conservation of mass and balancing chemical equations. The following examples taken from this part of the test illustrate some of the differences in the test responses between treatment and control group. Students were asked to draw pictures representing the particles in the chemical reaction. The following question is representative of a question from part 2 of the test.

Sample Question: The balanced equation for the decomposition of water is:

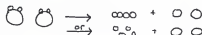


Show how the reaction would look using the following symbols. Let $\bigcirc$ stand for oxygen and $\bullet$ for hydrogen atoms. Draw the atoms/molecules for the reaction and describe the reaction in terms of atoms and molecules.

Typical answer:



Several items distinguished the students in the treatment group from those in the control group. First, the majority of treatment students showed conservation of mass with the particles on their drawings. That is to say, their drawings indicated equal number of particles on both sides of the chemical equation. Second, their drawings also correctly indicated which particles in the reactions were atoms and which were molecules. This mastery is important for the comprehension of further chemical concepts. Students from the control group were less likely to exhibit these responses. Quite often they did not even attempt to answer the questions. Examples of their answers to the question are below:



Information derived from one teacher's comments indicated that the students began to visualize the orientation or three dimensional structure of the substance. While working with the magnets to balance equations, students asked the teacher questions relating to bonding, bond orientation, and structural geometry of the molecules. For example, when they placed two magnets together to represent a molecule, they asked what type of bond held the two particles together. Students also asked how the atoms should be arranged when putting several of these magnets together to make a compound. This second question was asked of all three teachers. The teachers commented that the practice with magnets enhanced student comprehension of the above topics when these topics were taught at a later date.

This study confirms the results of Yarroch (1986) and Gabel and Schrader (1987) in that traditional chemistry instruction does not emphasize the underlying concepts related to conservation of mass and balancing equations. Students come out of chemistry classes able to balance equations without understanding the reactions at the molecular level. Students in both the control and experimental group could balance equations given the basic equation. The study indicates that an effective way to enhance comprehension of atoms and molecules is to use three dimensional models. Also the models were used for all three instructional levels: phenomena, symbolic and abstract. Instruction with models should link the concept to the actual reaction observed by the students, to the symbolic representation and to the atomic/molecular description of the reaction.

The interviews allow us to look at some common misconceptions relating to balancing equations and conservation of mass. Many students could not tell

the difference structurally between atoms and molecules. They could give definitions but could not apply these definitions to applications. Also they did not understand the implications of the conservation of mass law to balanced chemical equations. When asked what it means for a chemical equation to be balanced most said "It's equal on both sides," and they did not know what "it" was. They often said the molecules were equal. Students did not understand the significance of coefficients in balancing equations either. In the equation $2 \text{ Mg} + \text{O}_2 \implies 2 \text{ MgO}$, many students did not understand what the number "2" represented and how to use it in balancing equations.

2. There was a significant relationship between formal reasoning ability and content performance independent of treatment. In all analyses run, this variable indicated the highest significant relationship of all the mediating variables. As can be seen from Table 4-4A, the majority of the students were at the concrete level. This finding supports the results of Bitner-Corven (1989) and Herron (1990). In order to understand the concepts being taught, these students required the use of concrete, hands-on manipulatives.

The concepts of conservation of mass, balancing chemical equations and atomic structure are all topics that require students to visualize microscopic particles and then perform manipulations on these particles. Students at the concrete level find it difficult or impossible to understand these ideas. Many other concepts taught in chemistry also require a higher level of thinking and reasoning. Abstract concepts and ideas are usually developed without providing a concrete base to help the student's comprehension. Instruction is frequently based on the memorization of these ideas without demonstrating the atomic/molecular structure that underlies these concepts. As a result students

at the concrete level of reasoning rarely have success in traditional chemistry instruction (Cantu & Herron, 1978, Lawson & Renner, 1975). Further tests need to be done to see which instructional type benefits these students the most.

The highest scores on the achievement posttest were obtained by the students in the low formal reasoning group (Group 4). These students also had the highest scores on each of the test parts. Achievement scores at each of the extremes of the formal reasoning levels may not have been reliable, as the sample sizes for these groups were small, which may explain why the achievement in the high formal reasoning group was lower than the achievement in low formal reasoning group. It also may explain why the low concrete students had higher achievement scores on part 2 content of the achievement test than the high formal reasoning group.

3. There was a significant relationship between each of the three spatial visualization tests and content performance. However, in the analysis with all three tests in the model only the Form Board Test and Hidden Figures Test were significant. The Card Rotation Test was dropped from the model.

Each of the three visualization tests examined an important skill that is used in chemistry. The Form Board Test measures a student's ability to put pieces together to make a whole. Three dimensional manipulation and rotation of objects is a skill often used in making new chemical compounds. The Hidden Figures Test examines a student's ability to disembed a shape from a more complex shape. This skill is used in the medical field, during surgery, and in chemistry research in developing designer drugs and developing antibodies for viruses. In high school chemistry, students can look at a three dimensional molecule and see what component parts make up the molecule. For example, they may see a hydroxyl group attached or note three nitrate ions are attached

in the whole compound. Chemistry comprehension can be enhanced by having better visualization skills. For example, if students are able to visualize the atomic/molecular level of molecular motion, they can take this information and better apply it to more complex ideas such as gas laws or solution chemistry. Thirty-one percent of the variance in the posttest scores was due to visualization skills.

An analysis was done to examine the effect of instruction on visualization skill. A new variable was calculated from the three independent visualization variables and was used to classify students as low/medium or high visualizers. Students classified as low visual in both the control and experimental groups had lower scores on the achievement test. This finding indicates that if students do not have good visualization skills already, they will not have high achievement regardless of the instruction. However, students with medium and high levels of visualization skills had enhanced achievement on the content test when instruction was visual.

4. Is there a difference in content performance related to the combined effect of instructional method, reasoning ability, and visualization?

Analysis of the content performance as the dependent variable and precontent scores, reasoning ability and visualization skills, as independent variables, was done to examine this question. It was found that chemistry achievement as measured by the post content test was significantly related to the Formal Reasoning test scores, the Hidden Figures test scores and the precontent test scores. It could not be significantly predicted by the Form Board Test or the Card Rotation Test. When the method of instruction was included in the analysis, again only the Hidden Figures and Formal Reasoning test scores were significantly related to chemistry achievement.

Cantu and Herron (1978) and Gabel and Samuel (1990) showed that formal reasoning is significantly related to chemistry achievement. This study corroborates their findings. Examination of correlation coefficients for the posttest scores and formal reasoning scores gives the following information. The correlation coefficient between total post test scores and formal reasoning scores was 0.50, a moderate correlation. Part 2 of the posttest showed the highest correlation, 0.53, to formal reasoning. Part 2 of the posttest examined the concept of atoms and molecules in balancing equations and conservation of mass, an abstract concept for students to grasp.

Implications for Curriculum and Instruction

For the topic of balancing equations and conservation of mass, a hands-on, visual approach enhances chemistry comprehension at all three levels of knowledge from the phenomenological to the atomic/molecular. By combining instruction that provides microscale laboratory experiments with symbolic and three dimensional modeling, students better understand the concept. Students in the treatment group gave significantly more correct answers on part 2 of the posttest content test. Instruction by teachers needs to include all three of these levels of chemistry knowledge (phenomenological, symbolic, and atomic/molecular) in this topic as well as other topics.

An important linking of this concept to other concepts takes place from students constructing these three dimensional models. Students start asking questions about the structure/function relationship in chemistry. Using images of molecules helps them to see how molecular structure affects such concepts as reaction dynamics, rates, energies, and solubilities.

2. How do students learn the information (e.g., facts, concepts) that make up chemistry?

Traditional chemistry instruction focuses on the algorithm of balancing equations. Students typically memorize the algorithm and then use it. They do not make the link between what they see in a laboratory experiment and what is written symbolically. After a period of time, usually less than 2 weeks, the algorithm is forgotten and students do not remember how to balance equations. This became very obvious when the content test was initially field tested with two chemistry classes. These classes had studied conservation of mass and balancing equations within the last 2 weeks. Student achievement on the test was approximately 20-25%, indicating they had quickly forgotten the material.

Postinstruction interviews with students from the control group showed that they could not balance equations easily. They could not describe the particles that made up the chemical equation in terms of atoms or molecules, and when asked to explain the law of conservation of mass, numerous students said they did not know what it was.

During the follow-up interviews, students were asked to transcribe a chemical word equation into a symbolic equation, balance it, and describe the particles. For example, this word equation was used: Magnesium reacts with oxygen to yield magnesium oxide. Students in both control and experimental groups had some difficulty performing this task. They could write the symbols for the elements, magnesium and oxygen. Rarely did they show oxygen as a diatomic molecule. The formula for magnesium oxide was also misrepresented. Two common examples of answers for this reaction from students were



The second answer shows a misconception regarding how ions (charged atoms) combine to form a compound. Only two of the students in the experimental group and none in the control group were able to perform this task. Students did not correctly balance charges in writing the chemical formula. Writing these equations utilized concepts that had been taught previously: differences between atoms and molecules and writing formulas. These are abstract concepts and are difficult for students to master. One can assume they did not comprehend the topic of writing formulas.

Because the students forget the chemistry concepts fairly rapidly, a curriculum that allows for the topics to be reinforced periodically throughout the text would be beneficial. The textbook Chemistry in the Community published by the American Chemical Society is one attempt to do this. This textbook also provides a Science-Technology-Society basis for instruction. Also a new textbook, Visualizing Chemistry by Holt is currently using numerous two dimensional and three dimensional atomic/molecular models throughout the book to explain the concepts. This study leads to the hypothesis that these new formats will improve comprehension for more students.

It is also important to note that students who are not visually oriented do not do as well with a visual presentation. Howard Gardner (1993) proposed that students have multiple intelligences and multiple learning styles. This reinforces the idea that using only one method of instruction is insufficient to reach all students. Teachers must make an effort to include instructional methods that meet the needs of all their students.

3. What barriers limit students from achieving in chemistry?

From the data analysis, two factors seem to affect student achievement in chemistry on the topics presented. These two factors are formal reasoning skills

and visualization skills. Approximately 25% of the variance in the chemistry achievement test could be explained by the formal reasoning scores.

Because numerous concepts in chemistry are at the abstract level, students at lower levels of reasoning often do not comprehend the concepts or develop misconceptions. By measuring the formal reasoning levels of students prior to instruction, the instructor can assist in student comprehension. Instruction can provide concrete items for the student to use in bridging to the abstract idea. Activities and lessons should be developed to move the student from the concrete into the formal level of reasoning.

Visual spatial skills also affected the chemistry achievement. This supports research by Barke (1993) who found that students who exhibited greater visualization skills achieved higher scores on chemical structures. These skills vary from visual observations to manipulation of 2-dimensional and 3-dimensional objects. Approximately 31% of the variance in the posttest score could be explained by the scores on the spatial visualization test scores. It turns out that for students who tested as strong on visualization skills, the treatment helped.

Forty-one percent of the variance could be explained by the formal reasoning and spatial visualization measures. The study indicates that these are two key barriers to student achievement in chemistry. The final analysis shows that the teacher was significantly related to chemistry achievement. The posttest achievement scores for one teacher were significantly higher than they other two teachers. Even though a curriculum guide was provided, the teachers may not have followed it exactly. This brings to mind the problems encountered with the science curriculum projects in the 1970's. Most of these curriculum projects were not successful due to lack of training and continuation of feedback

for teachers. Even with a desire to change teaching styles, it is difficult for teachers to deviate from a method that they have used in the past. Another possible reason is that the teachers themselves had difficulty making the connections between the phenomenological, symbolic and atomic/molecular levels of instruction.

Conclusions

Further research in other chemistry topics using a visual spatial means of instruction is needed to determine if certain visual spatial skills are used in different chemistry topics. For example, the Card Rotation test was not significantly related to achievement on the topic of balancing equations and conservation of mass. However, it may be more strongly related to other chemistry topics. Other visualization tests need to be developed for the different visual spatial skills as described by McKim (1980) and McCormick (1988).

Instruction techniques, taking into account the reasoning level and possibly the visualization level of students, should be developed and tested. Students at the concrete level should be provided hands-on concrete materials to work with when studying abstract concepts. Every measure should be taken during instruction to help students make links between the phenomenological, symbolic, and atomic/molecular level of knowledge comprehension.

Research has also shown that visualization skills can be learned. Students should be given numerous opportunities to practice visualization skills. Observing a reaction, graphing gas relationships, and examining molecular structure are all visualization skills that are used in chemistry. Continued practice in all areas would help develop these skills.

The research in these two areas has been sporadic and ranges over a 20

year period. Most of the research has taken place at the college level, with little emphasis on high school students. The type of instruction necessary for higher achievement in chemistry has only been examined for a few topics. All of these factors gives rise to a real need for more collaborative research on the questions stated earlier in chapter 2.

APPENDIX A
CURRICULUM GUIDE

TOPIC: BALANCING CHEMICAL EQUATIONS AND CONSERVATION OF MASS

OBJECTIVES

INSTRUCTIONAL

1. To define chemical reaction and list the reactants and products in a given reaction.
2. To use the correct symbols for the physical state of each substance involved in chemical equations.
3. To distinguish a chemical reaction from a chemical equation and state what it means for an equation to be balanced.
4. To distinguish subscripts and coefficients in chemical equations.
5. To write balanced equations given names and/or formulas for reactants and products.
6. To classify a given reaction as one of these four types: single replacement, double replacement, decomposition or synthesis.
7. To define each of the four types of reaction.
8. To predict the products and balance the equation when given the reactants for one of these four types of reactions.
9. To define stoichiometry
12. To differentiate the characteristics of exothermic and endothermic reactions.

LABORATORY

1. To determine experimentally whether mass is conserved in a particular set of chemical reactions.
2. To observe some chemical reactions and identify reactants and products of those reactions.
3. To classify the reactions and write balanced equations.
4. To find the ratio of moles of a reactant to moles of a product in a chemical reaction. To relate this ratio to the coefficients of these substances in the balanced equation for the reaction.

5. To compare the experimental mass of a product of a chemical reaction with the mass predicted for that product by calculation.
6. To compare the theoretical mass of one of the products of a double replacement reaction with the experimentally determined mass of the same product.

MATERIALS AND EQUIPMENT

The following materials and equipment are needed for instruction of this topic. Quantities are given for two students per lab group.

EXPERIMENT	EQUIPMENT	MATERIALS
CONSERVATION OF MASS		
LAB 9	Balances	1 M Na_2CO_3
	Erlenmeyer flask (125 ml)	1 M CaCl_2
	Rubber stopper	1 M H_2SO_4
	Graduated cylinders	
	test tubes (2)	
	Corks for test tubes	
	Safety goggles and apron	
TYPES OF CHEMICAL REACTIONS		
LAB 14	Burners	Mossy Zinc
	Crucible tongs	Copper Wire(10 cm)
	Spatula	Mg ribbon (5 cm)
	test tubes (7)	CuCO_3
	Test Tube Holder	6 M HCl
	Test Tube Rack	1 M CuSO_4
	Wood splints	0.1 M $\text{Zn}(\text{C}_2\text{H}_3\text{O}_2)_2$
	Fine sandpaper	0.1 M Na_3PO_4
	Evaporating dish	1 M Na_2SO_4
	Safety goggles and apron	

RELATING MOLES TO COEFFICIENTS OF A CHEMICAL EQUATION

LAB 15	Balance	CuSO_4
	Burner	Iron filings
	Beakers (100 & 250 ml)	
	Graduated cylinder	
	Ring stand and ring	
	Wire gauze	
	Glass stirring rod	
	Safety goggles and apron	

MOLE AND MASS RELATIONSHIP

LAB 16	Balance	6 M HCl
	Burner	NaHCO_3
	Evaporating Dish	
	Watch Glass	
	Spatula	
	Test Tube	
	Dropper pipette	
	Ring stand and ring	
	Wire gauze	
	Safety goggles and apron	

MASS-MASS RELATIONSHIPS IN REACTIONS

LAB 17	Balance	$\text{Zn}(\text{C}_2\text{H}_3\text{O}_2) \cdot 2\text{H}_2\text{O}$
	Graduated cylinder	$\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$
	Beakers (250 ml) - 2	Distilled water
	Beaker (100 ml)	
	Stirring rod	
	Ring stand and ring	
	Funnel	
	Filter paper	
	Safety goggles and apron	

HEAT OF REACTION

LAB 15	Balance	NaOH (s)
	Spatula	1.0 M NaOH
	Thermometer	1.0 M HCl
	Graduated cylinder	0.5 M HCl
	Styrofoam cups	Safety goggles and apron

INSTRUCTIONAL CURRICULUM

Day 1	10 min	1. Introduction to chemical reactions A. Demonstration: Burning of Magnesium (Remind students not to look directly at the burning magnesium.) Have students take observations and go over them. Reinforce definition of chemical reaction/chemical change. B. Write word equation of reaction on board. (Magnesium reacts with oxygen to produce magnesium oxide.) •Ask students what information you can get from word equations. (Limit to information - can get more information from equation written in symbols.)
	10 min	C. Write symbols of reaction on board. ($\text{Mg(s)} + \text{O}_2\text{(g)} \rightarrow \text{MgO(s)}$) •Introduce terms and symbols used in writing equations. (Example: s, l, g, +, ==>, reactants, products, etc.) •Reinforce a chemical reaction is a chemical change where there is a change in properties and arrangement of atoms. D. Atomic Models • Use models/magnets to represent equation either on the board or overhead. Have students use their magnets to do the same. • Remind students the magnets are just a visual tool/model to help us understand what is going on in a reaction. Each magnet represents an atom.
	15 min	E. Example 2: Demonstration - Electrolysis of water •Have students take observations and discuss. • Write the word equation on the board. (Water decomposes into oxygen and hydrogen.) • Have the students transcribe the word equation into a symbolic equation.

- Students should do the reaction with models/magnets to reinforce the reaction.**
- 10 min F. Review the concepts.
 Q. What is the difference between a word equation and a chemical equation?
 Q. What information can be derived from a chemical equation?

Homework: Worksheet 1 (Transcription of word equations into chemical equations and drawing of models to represent equations.) Read Lab 9 and do Prelab sheet.

- Day 2:
- 5 min. Collect homework.
 Check pre-lab sheet.
- 30 min •Lab 9: Conservation of Mass
 Students will perform lab 9 from Prentice-Hall. They will work in pairs to do the lab.
- 10 min •Post lab discussion of conservation of mass and how it relates to writing equations.
- 10 min •Use models to show how the conservation of mass law applies to balancing equations. Use this lab's reaction for example.

Homework: Finish the Lab questions and calculations.
 Have lab ready to turn in tomorrow.

- Day 3:
- 5 min Collect lab reports.
- 10 min •Review how Empirical data allows us to Balance Chemical Equations -
 Class discussion - Question and answer format
- 5 min •Introduction of rules relating to balancing equations (p.148 in Chemistry, Addison-Wesley)
 Introduce terms such as coefficient,

- subscripts, etc.
- 10 min •Symbolically show conservation of mass with reaction run in demonstration #1
- $$2 \text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$$
- Have students work with magnets/models to balance the equation.**
- Students check work after teacher does it on the board or overhead. Do the same as above for demonstration #2
- $$2 \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{O}_2$$
- 20 min •Pass out microscale equipment and chemicals. Do 2-3 microscale reactions on the overhead and at desks. Have students write observations. Students should relate the qualitative observations to the chemical reaction and symbolic equation.
- Students should use models/magnets to visually see this relationship.**
- Examples:
1. $\text{NaCl} + \text{AgNO}_3$
 2. $\text{Ba}(\text{NO}_3)_2 + \text{NaOH}$
 3. $\text{Zn} + \text{HCl}$

Homework: Worksheet #2 Balancing Equations/Conservation of Mass

Note: The Experimental group will have extra pages dealing with visualization of atoms and molecules.

Day 4 Topic: Energy Changes with Reactions

- 10 min **A. Brief Introduction to the idea of endothermic and exothermic reactions. Use a ziplock bag to run the reactions in to demonstrate qualitatively the two**

	types of reaction. Pass the bags around and have students feel them. If possible use the new sports heat and cool bags, students can see the everyday applications of this idea. Examples: NaOH pellets in water for the exothermic and baking soda and vinegar for the endothermic.
5 min	B. Define and break the words apart for comprehension.
15 min	C. Write word equations on board with energy units, transcribe to chemical equation. Have students use magnets/models to represent the balanced equation and put their answers on the board.
	D. Work several other examples where energy is written into the equation or ΔH value is given. Have students determine if they are exothermic or endothermic.
5 min	E. Review concepts covered. F. Pass out pre-lab sheet for Lab

Homework: Worksheet #3 - Balancing Equations with energy terms

Day 5: Lab - Heat of Reaction

5 min	Collect homework. Check pre-lab sheet. Go over safety and instructions.
40 min	Lab
15 min	Begin post lab discussion. Have students go over first the qualitative observations (i.e. solution got hot or cold). Continue the next day the rest of the postlab discussion if needed.

Homework: Finish Lab report for Day 8.

Day 6: Topic -- Types of Reactions

- | | |
|--------|--|
| 10 min | Finish post lab discussion for the previous lab. Answer any questions student may have about the lab report. |
| 5 min | <p>Introduction to types of reaction:
 Ask students for some examples of material that has used the process skill of classification before.
 (Student answers).
 Tell them that chemists classify reactions into different types depending on types of starting reactants and ending products. This is another tool to help them understand about reactions, etc.</p> |
| 30 min | <p>Describe the first two types of reactions (synthesis and decomposition) using the following procedure.</p> <ol style="list-style-type: none"> a. Show an example on the video/videodisk or do a demonstration. b. Ask students about their observations. c. Give the definition using an example (if possible the one on the video/videodisk) <p>• Write the word equation for the reaction:
 EXAMPLE: Sulfur reacts with oxygen to yield sulfur dioxide.</p> <p>• Have the students transcribe into the symbolic equation: EXAMPLE:
 $S + O_2 \rightarrow SO_2$</p> <p>• Have the students use models/magnets to represent the reaction atomically and molecularly.</p> |

- d. Give the general equation for the reaction.
 $R + S \Rightarrow RS$
 e. Do 2-3 other examples:
 Teacher does it
 microscale/demo and students
 write reactions.
**Experimental group also uses
 magnets for models.**
 Review the above concepts with
 the students.
- 15 min

Day 7: Continuation of Types of Reactions

- 5 min Collect lab reports.
- 5 min Review concepts covered
 yesterday.
- 30 min Introduction of the next two types of
 reaction (single and double
 replacement reactions). Follow the
 same procedure from the day
 before:
 a. Example
 b. Definition
 c. Writing the equation.
Do with magnets.
Experimental group
only.
 d. Give general equation
 e. Do 2-3 microexamples as
 demo/student
 activities.
- 15 min Pass out worksheet for homework
 due in two days. Students should
 begin and teacher assist them if
 they have any questions. Pass out
 prelab worksheet for Lab: Types of
 Chemical Reaction.

Day 8: Topic - Continuation of Reaction Types

20 min	Review the types of reactions. If possible have demos/video/videodisk examples available to show students. Practice identifying them, writing the equations and for the experimental group depicting them in molecular/atomic format.
20 min	Students work on worksheet due for tomorrow. Teacher assists students with any questions.
15 min	Pre-lab discussion for Types of Chemical Reactions Lab. Discussion should focus on safety/procedures

Day 9: Topic -- Types of Chemical Reaction Lab

5 min	Check prelab sheet.
35 min	Lab- microscale lab
10 min	Assign lab questions for homework.

Day 10: Topic - Lab discussion

20 min	Post lab discussion - Use models to discuss reactions, write the reactions symbolically and balance. Experimental group work with magnets.
35 min	Pass out review sheet. Review key concepts: • conservation of mass • energy changes in reactions

- types of reactions

Relate each of the above to the three concept levels:

phenomena, symbolically, and atomic/molecularly.

Practice balancing equations with students and identifying the type of reactions

Day 11: Topic

Review

15 min

Grade homework. Review concepts again.

Go over any conceptual problems the students might have after grading the homework.

30 min

Students work in groups of two to study and help each other prepare for test. Students are given a list of objectives for test they can study from.

Day 12: Topic

Chapter Test

55 min

See attached sheet for copy of test.

APPENDIX B
CONTENT TEST

Chemistry Test

Name: _____

Teacher: _____

Date: _____

Period: _____

Part I: Multiple Choice

1 point each

Directions: For each of the following, choose the correct answer and place the letter in the blank space to the left. There is only one correct answer per question.

_____1. In a chemical reaction the mass of the products:

- a. is less than the mass of the reactants
- b. is greater than the mass of the reactant
- c. is equal to the mass of the reactants
- d. has no relationship to the mass of the reactants

_____2. The equation $\text{H}_3\text{PO}_4 + 3 \text{KOH} \rightarrow \text{K}_3\text{PO}_4 + 3 \text{H}_2\text{O}$ is an example of:

- a. double replacement reaction
- b. synthesis or combination reaction
- c. decomposition reaction
- d. single replacement reaction

_____3. The symbol Δ in a chemical equation means:

- a. heat is supplied or evolved in the reaction
- b. a catalyst is needed
- c. yields
- d. precipitate

_____4. The following equation shows the reaction that occurs when nitroglycerine explodes.



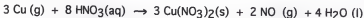
This reaction is:

- a. endothermic.
- b. exothermic.
- c. a combination reaction.
- d. a combustion reaction.

_____5. In any chemical reaction, the quantities that are conserved are:

- a. the number of moles and the volumes.
- b. the number of molecules and the volumes.
- c. mass and the number of atoms.
- d. mass and the number of moles.

_____6. If it were possible to drop 12 atoms of copper into a beaker containing nitric acid, how many molecules of NO would be produced? The chemical reaction for this is:



- a. 2
- b. 4
- c. 8
- d. 12

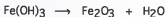
_____7. The new substances formed in a chemical reaction are referred to as:

- a. catalysts.
- b. intermediates.
- c. products.
- d. reactants.

_____8. Which of the following may be changed when balancing chemical equations?

- a. oxidation numbers
- b. subscripts
- c. atomic numbers
- d. coefficients

_____9. What coefficient should be placed before water when the following equation is balanced?



- a. 3
- b. 2
- c. 6
- d. 4

_____10. The general form for a double replacement reaction is:

- a. element + compound $\rightarrow$ element + compound
- b. compound + compound $\rightarrow$ compound + compound
- c. compound $\rightarrow$ two or more elements or compounds
- d. element or compound + element or compound $\rightarrow$ compound

_____11. As a student reacts zinc and hydrochloric acid in a flask, he observes that the flask becomes hot. He should classify this reaction as:

- a. thermonuclear
- b. synthesis
- c. endothermic
- d. exothermic

_____12. $\text{H}_2 + \text{Cl}_2 \rightarrow 2 \text{HCl}$ is an example of what type of reaction?

- a. synthesis
- b. single replacement
- c. decomposition
- d. double replacement

_____13. $2\text{KClO}_3 \rightarrow 2\text{KCl} + 3\text{O}_2$ is an example of what type of reaction?

- a. synthesis
- b. single replacement
- c. decomposition
- d. double replacement

Part II: Fill in the Blank. 1 point each

Directions: For the following section, complete the sentences with the correct word(s) or phrase(s).

14. A reaction that involves the interchange of the positive and negative ions of two compounds is:

15. A chemical reaction that absorbs heat and results in products that are higher in energy than the reactants is:

16. What does it mean to refer to an equation as "balanced"?

17. Describe the following reaction in terms of molecules and atoms. $2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2$

Part III: Balancing 2 point each

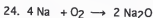
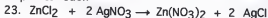
Directions: Balance the following equations and tell what type of reaction it is:



22. A student placed 8.25 grams of aluminum metal into an aqueous hydrochloric acid solution. All of the aluminum reacted to form aluminum chloride and hydrogen gas. No precipitate was observed. The student later evaporated the water to leave solid aluminum chloride. Write the balanced equation for the above reaction and use the correct symbols for the physical state of each substance involved.

Part IV. Types of Reactions

Directions: For each of the following reaction tell what type of reaction it is and name each product and reactant. 2 points each





Part V: 10 points total

Directions : Read the explanation for each of the following and draw the particles indicated.

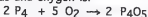
Particles interact with one another in chemical reactions. The coefficients in a balanced equation show the lowest number of atoms and molecules that react with one another leaving no particles left over.

27. The balanced equation for the decomposition of water is:



Show how the reaction would look using the following symbols. Let O stand for oxygen atoms and • for hydrogen atoms. Draw the atoms/molecules for the reaction using O and •. Example = H_2O is . Describe the reaction in terms of atoms and molecules.

28. The balanced equation for the reaction of phosphorus and oxygen is:



Show how the reaction would look in terms of using O for phosphorus atoms and • for oxygen atoms. Describe the reaction in terms of atoms and molecules.

29. The compound and element in Box A react to form a different element and one new compound. Draw what happened in the reaction in Box B. Write a balanced equation for the reaction.

Box A



Box B



Equation: _____

Chemical substances react in definite proportions by mass. On the molecular level, atoms react with one another resulting in different combinations of atoms in which particles and mass are conserved.

30. In reality, many molecules of water decompose, not only the two shown in the balanced equation. Show how 10 water molecules in the liquid state decompose to form gaseous hydrogen and oxygen using pictures. Let  equal water molecules.

31. Solid carbon burns in oxygen gas to form carbon dioxide gas. Start with 10 carbon atoms, and use pictures to show the complete reaction. Let  equal carbon and  equal oxygen atoms.

32. Carbon dioxide gas, (CO_2), reacts with solid carbon, (C) to form carbon monoxide, (CO). Draw pictures representing 5 atoms of carbon reacting with sufficient carbon dioxide to form carbon monoxide. Let $\bullet$ equal carbon and O equal oxygen atoms.

APPENDIX C
STUDENT INTERVIEW SHEET

PART 1: HERE IS A WORD EQUATION, PLEASE REPRESENT IT IN SYMBOLS. USE THE MAGNETS TO HELP YOU. TALK THROUGH THE EXERCISE AS YOU ARE DOING IT PLEASE.

Iron reacts with oxygen to give iron (III) oxide.

(Tell me how you got that.-Interviewer comment)

PART 2: HERE ARE SOME EQUATIONS WRITTEN IN SYMBOLS. CAN YOU MODEL THIS EQUATION USING THE MAGNETS FOR ME? TALK THROUGH WHAT YOU ARE DOING AS YOU DO IT PLEASE.



APPENDIX D CORRELATIONS

Correlations

Variable	atfr	precon1	precon2	form	hidden	cardrot	Postcon1	postcon2	TotPost	totpreconcent	TotNvitz
atfr	1.0000										
precon1	-0.0104	1.0000		0.4017	0.3347	0.2639	0.4171	0.5380	0.5027	0.6420	0.4891
precon2	0.2034	0.4100	1.0000	0.1758	-0.2184	0.0842	0.2492	0.0283	0.1841	0.3734	-0.0818
form	0.4017	0.1758	0.0854	1.0000	0.0065	0.0012	0.1202	0.2583	0.1888	0.3734	0.0255
hidden	0.3347	-0.2184	0.0654	0.0065	1.0000	0.3387	0.3280	0.3537	0.3708	0.1885	0.3694
cardrot	0.2639	0.0842	0.0012	0.2058	0.0782	1.0000	0.3271	0.4843	0.4225	-0.1885	0.4115
Postcon1	0.4171	0.2492	0.0012	0.3387	0.3271	0.3280	1.0000	0.2488	0.2349	0.0735	0.5117
Postcon2	0.5380	0.0283	0.1202	0.2583	0.3537	0.4843	0.8318	1.0000	0.9502	0.2471	0.4187
TotPost	0.5027	0.1841	0.1888	0.3708	0.4225	0.2349	0.8419	1.0000	1.0000	0.2071	0.5159
totpreconcent	0.6420	0.3734	0.1885	0.0735	-0.1885	0.0735	0.2471	0.0873	1.0000	0.2071	-0.0848
TotNvitz	0.4891	-0.0818	0.0255	0.3694	0.4115	0.5117	0.4187	0.5815	-0.0848	1.0000	

Table 1.
Correlation coefficients

APPENDIX E
ANALYSIS OF PART 1 & 2 POSTTEST
& ATFR CODE

Mean Estimates				
Level	number	Mean	Std. Error	
1	5	4.00000	1.7531	
2	40	2.25000	0.6198	
3	19	4.94737	0.8993	
4	14	9.57143	1.0477	
5	7	5.71429	1.4816	

Means Comparisons						
Df=Mean(I)-Mean(J)	4	5	3	1	2	
4	0.00000	3.85714	4.62406	5.57143	7.32143	
5	-3.85714	0.00000	0.76692	1.71429	3.46429	
3	-4.62406	-0.76692	0.00000	0.94737	2.69737	
1	-5.57143	-1.71429	-0.94737	0.00000	1.75000	
2	-7.32143	-3.46429	-2.69737	-1.75000	0.00000	
Alpha= 0.05						
Comparisons for all pairs using Tukey-Kramer HSD						
q*						
2.79097						
Abs(Df)-LSD	4	5	3	1	2	
4	-4.13515	-1.20736	0.77055	-0.12848	3.92406	
5	-1.20736	-5.84798	-4.07036	-4.69185	-1.01811	
3	0.77055	-4.07036	-3.54959	-4.55163	-0.35094	
1	-0.12848	-4.69185	-4.55163	-6.91942	-3.43957	
2	3.92406	-1.01811	-0.35094	-3.43957	-2.44639	
Positive values show pairs of means that are significantly different.						

Table 1.
Analysis of Part 1 Posttest and ATFR Code

Mean Estimates				
Level	number	Mean	Std. Error	
1	5	18.4000	3.1961	
2	40	19.3750	1.1300	
3	19	24.2632	1.6396	
4	14	26.0000	1.9100	
5	7	20.4286	2.7012	

Means Comparisons						
Df=Mean(I)-Mean(J)	4	3	5	2	1	
4	0.00000	1.73684	5.57143	6.62500	7.60000	
3	-1.73684	0.00000	3.83459	4.88616	5.86316	
5	-5.57143	-3.83459	0.00000	1.05357	2.02857	
2	-6.62500	-4.88616	-1.05357	0.00000	0.97500	
1	-7.60000	-5.86316	-2.02857	-0.97500	0.00000	
Alpha= 0.05						
Comparisons for all pairs using Tukey-Kramer HSD						
q*						
2.79097						
Abs(Df)-LSD	4	3	5	2	1	
4	-7.5389	-5.2886	-3.6618	0.4311	-2.7917	
3	-5.2886	-6.4714	-4.9844	-0.6693	-4.1622	
5	-3.6618	-4.9844	-10.6616	-7.1184	-9.6507	
2	0.4311	-0.6693	-7.1184	-4.4601	-8.4863	
1	-2.7917	-4.1622	-9.6507	-8.4863	-12.6150	
Positive values show pairs of means that are significantly different.						

Table 2.
Analysis of Part 2 Posttest and ATFR Code

APPENDIX F
ANALYSIS OF TOTAL POSTTEST & ATFR CODE

Mean Estimates

Level	number	Mean	Std Error
1	5	22.4000	4.5503
2	40	21.6250	1.6088
3	19	29.2105	2.3342
4	14	35.5714	2.7193
5	7	26.1429	3.8457

Means Comparisons

Dif=Mean[i]-Mean[j]	4	3	5	1	2
4	0.0000	6.3609	9.4286	13.1714	13.9464
3	-6.3609	0.0000	3.0677	6.8105	7.5855
5	-9.4286	-3.0677	0.0000	3.7429	4.5179
1	-13.1714	-6.8105	-3.7429	0.0000	0.7750
2	-13.9464	-7.5855	-4.5179	-0.7750	0.0000

Alpha= 0.05

Comparisons for all pairs using Tukey-Kramer HSD

q*
2.79097

Abs(Dif)-LSD	4	3	5	1	2
4	-10.7332	-3.6413	-3.7169	-1.6233	5.1282
3	-3.6413	-9.2133	-9.4880	-7.4627	-0.3267
5	-3.7169	-9.4880	-15.1790	-12.8849	-7.1167
1	-1.6233	-7.4627	-12.8849	-17.9601	-12.6951
2	5.1282	-0.3267	-7.1167	-12.6951	-6.3498

Positive values show pairs of means that are significantly different.

Table 1.
Analysis of Total Posttest and ATR Code

APPENDIX G
ANALYSIS OF PART 1 POSTTEST
& VISUALIZATION SCORES

Source	DF	SS	Mean Square	F Ratio
Model	1	836.7	836.7	15.90
Error	110	5787.58	52.61	Prob>F
Total Error	111	6624.28		0.0001

Table 1.

General Linear Model for the Form Board Test and Part 1 Posttest Score

Source	DF	SS	Mean Square	F Ratio
Model	1	530.01	530.01	9.41
Error	106	5968.99	56.31	Prob>F
Total Error	107	6499.00		0.0027

Table2.

General Linear Model for the Hidden Figures Test and Part 1 Posttest Score

Source	DF	SS	Mean Square	F Ratio
Model	1	211074	211.74	3.61
Error	108	6339.03	58.70	Prob>F
Total Error	109	6550.77		0.0602

Table 3.

Linear Model for the Card Rotation Test and Part 1 Posttest Score

APPENDIX H
ANALYSIS OF PART 2 POSTTEST
& VISUALIZATION SCORES

Source	DF	SS	Mean Square	F Ratio
Model	1	293.71	293.71	18.17
Error	110	1777.72	16.16	Prob>F
Total Error	111	2071.43		0.0000

Table 1.
General Linear Model for the Form Board Test and Part 2 Posttest Score

Source	DF	SS	Mean Square	F Ratio
Model	1	414.62	414.62	27.22
Error	106	1614.30	15.23	Prob>F
Total Error	107	2028.92		0.0000

Figure 2.
General Linear Model for the Hidden Figures Test and Part 2 Posttest Score

Source	DF	SS	Mean Square	F Ratio
Model	1	106.36	106.36	5.94
Error	108	1932.63	17.90	Prob>F
Total Error	109	2038.99		0.0164

Figure 3.
General Linear Model for the Card Rotation Test and Part 2 Posttest Score

APPENDIX I
ANALYSIS OF TOTAL POSTTEST
& VISUALIZATION SCORES

Source	DF	SS	Mean Square	F Ratio	Prob>F
Model	3	1172.37	391.79	7.51	0.0001
Error	102	5301.23	51.97		
Total Error	105	6473.59			
Form	1	514.87		9.91	0.0022
Hidden	1	307.49		5.92	0.0167
CardRot	1	17.73		0.34	0.5605

Table 1.
General Linear Model for All Visualization Tests and Part 1 (Content) Achievement
Posttest

Source	DF	SS	Mean Square	F Ratio	Prob>F
Model	3	607.53	202.51	14.54	0.0000
Error	102	1420.43	13.93		
Total Error	105	2027.96			
Form	1	113.22		8.13	0.0053
Hidden	1	303.67		21.81	0.0000
CardRot	1	27.46		1.97	0.1633

Table 2.
General Linear Model for All Visualization Tests and Part 2 (Visualization)
Achievement Posttest

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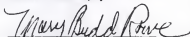
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BIOGRAPHICAL SKETCH

Cynthia Trexler Holland was born in Peru, Indiana, on August 2, 1948. She received her Bachelor of Science degree from Purdue University in 1972 with a major in chemistry. She returned to Purdue and added a science education major to her degree in 1973. In 1981 she earned a Master of Science degree in Science Education from Purdue University. She taught in Indiana for twelve years before moving to Florida in 1986. She began teaching in Alachua County and is presently employed by the Alachua County School Board as a chemistry teacher at Newberry High School.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.



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Professor of Instruction and
Curriculum

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.



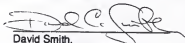
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Associate Professor of
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Professor of Instruction and
Curriculum

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David Smith,
Professor of Educational
Leadership

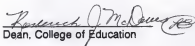
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This dissertation was submitted to the Graduate Faculty of the College of Education and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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